Oscillographic Investigation Of Current and E. M. F. Waves Of Telephone Magneto Generators

R. A. Morrison
David Lurvey
W. H. Reker

1907

537.82
M 83

ARMOUR
INST. OF TECH. LIB.
CHICAGO.

Illinois Institute
of Technology
Libraries

AT 83
Morrison, Rudolph A.
An Oscillographic
investigation of current

AN OSCILLOGRAPHIC INVESTIGATION OF CURRENT AND E. M. F. WAVES OF TELEPHONE MAGNETO GENERATORS

A THESIS

PRESENTED BY

RUDOLPH A. MORRISON
DAVID LURVEY
WILLIAM REKER

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED COURSE OF STUDY IN

ELECTRICAL ENGINEERING

1907

Chas E Snow
Acting Director

H M Raymond
Dean of Engineering

L. C. Monin
Dean of Cultural Studies

ILLINOIS INSTITUTE OF TECHNOLOGY
PAUL V. GALVIN LIBRARY
35 WEST 33RD STREET
CHICAGO, IL 60616

537.8
M15

AN OSCILLOGRAPHIC INVESTIGATION OF THE CURRENT AND E.M.F. WAVES OF TELEPHONE MAGNETO GENERATORS.

Introduction:

In order to ring a bell over a line containing a good deal of resistence, inductance, and capacity, it is seen that rather a large E.M.F. is necessary. Alternating current generators are universally used by all manufacturers, since they are easier and cheaper to manufacture, and do not get out of repair as easily as direct current generators.

The voltage of any generator depends upon the rate at which the lines of force due to the magnetic field are cut by the conductors of the armature as they revolve. The rate however, depends upon the area of the pole pieces, the intensity of the field, the number of turns of wire on the armature, and upon the speed of the later. The E.M.F. in volts is expressed by the following equation: $E = \frac{4 \cdot H \cdot A \cdot N \cdot S}{10^8}$

Where H is the intensity of the field in lines per square per sq.cem., A is the area in sq.cem. M is the number of turns of wire on the armature S is the speed in revolutions per second. The factor 4 is used because one loop or turn of wire cuts the field four times each revolution. 10^8 in the denominator is used to change from C.G.S. to practical units.

It can be seen from above equation that in order to design a telephone magneto generator that will produce a large voltage the quantities in the numerator are to be made a large as possible. These possibilities and their limitations are briedly enumerated.

19511

The intensity of the field depends upon the quality of the steel used in the bar magnets, and upon the grade of soft iron used in the pole pieces. Hard steel is very difficult to demagnetise, but will retain the magnetism once it is produced, hence it will not do to temper the magnets too strongly. On the other hand, soft steel is easily magnetised but easily loses its magnetism. It is therefore seen that these two properties work against each other, hence in order to produce a strong and permanent magnet the amount of tempering must be limited. The only way to increase the field is to use more magnets depending upon the purpose for which the generator is to be used. Usually there are from three to six magnets used: In the majority of cases five are used. The limit to the number of magnets is the cost and weight of the machine. The area of the field is also increased by using more magnets.

The number of turns of wire on the armature is limited by the size of the armature core and by the size of the wire. The turns can be increased by using a smaller size of wire, but this increase in resistance of the armature would tend to cut down the current considerably.

The speed is definitely determined by the fact that a person usually turns the crank about four or five times per second: It has also been found impractical to use as large a gear ratio as five to one, for increasing the speed of the armature. In the test on the generators, the armatures were driven at a constant speed of one thousand revolutions per minute, or sixteen and two third revolutions per second.

Measurement of voltage of Generator.

The voltage of the generator is usually measured by placing an ordinary A.C. voltmeter across the terminals of the macine, and reading the indicated voltage.The voltmeter uses a very small current for its operation. A telephone magneto generator has a small current output,and when a voltmeter is put across its terminal the instrument will act as a load on the generator and reduce the voltage.Hence the voltage read is lower than the true value by an amount depending upon the resistance of the voltmeter.

In order to measure the exact voltage of the machine,an instrument which consumes no current must be used.The electrostatic voltmeter is well adopted for the purpose.This instrument is operated by the action taking place between two changed bodies which require only an infinitesmal amount of current for the charging.

The voltage of each machine under test was measured with the Ayrtom and Mathers electrostatic voltmeter and with the Weston A.C.voltmeter.#3107.The Weston voltmeter contains two coils, one having a resistance of 2778.8 int.ohms,which gave a range to the scale from 0 to 150 volts:The other coil had a resistance of 1389.4 int. ohms,giving a range to the scale from 0 to 75 volts The following readings were taken on the electrostatic voltmeter and on both scales of the Weston voltmeter.

Table "1"

Machine.	Electrostatic Voltmeter.	0-150 V. scale.	0-75 Volt scale.
# 1	92.6	80	71
2	85.5	77	68.2
3	92	80	71
4	95.5	80	71
5	94.1	68	60
6	96.4	82.5	73
7	92	81	72
8	72.5	59	51.5
9	91.8	72.5	64.5
10	74	66.5	59

It is seen from the above data that the voltages as read on the Weston voltmeter are much lower than those read on the electrostatic voltmeter.Again the readings on 0-75 volt scale of the Weston voltmeter are lower than those on the 0-150 volt scale.The lower restistance used with the 0-75 volt coil increases the current in the circuit and hence lowers the potential difference across the terminals of the voltmeter. It is therefore seen that the ordinary type voltmeter is not a reliable instrument for measuring the effective voltage of a magneto generator.The measurement with the electrostatic voltmeter is rather difficult since this voltmeter is not direct reading. The instruement must calibrated and a calibration curve obtained,the readings are taken by the deflection of a mirror on a scale and read with a telescope.

Great care must be taken to have the scale on the telescope at the same distance from the mirror, both for the test and the calibration. A comparison of results as sown by Table # 1. will show the great advantage derived by the use of the electrostatic voltmeter for measuring the no load voltage. The electrostatic voltmeter is therefore recommended as the instrument to be used for measuring the voltage of telephone magneto Generators.

We now have sufficient data on hand to determine the inductance of the armature of the generator. When the Weston voltmeter was placed across the terminals of the generator it acted as a load on the machine and a current passed through the circuit. The reading of the voltmeter is the effective voltage applied to its terminals. If this reading is divided by the resistance of the instrument the effective current is obtained, since the induction factor of the instrument is so small that it can be neglected. The results are shown in Table # 2.

For a circuit containing inductance and resistance, the value of the alternating current is expressed by the equation

$$I = \frac{E}{\sqrt{R^2+(2\pi f L)^2}}$$

There I is the effective current, E is the total E.M.F. generated on no load, as obtained with the elctrostatic voltmeter, R is the total resistance in circuit, f is the frequency in cycles per second, L is the co-efficient of self induction in henrys.

From above equation the inductance L, can be calculated since the other factors are known. The results are shown in Table # 2.

TABLE #2

Determination of Inductance

No.	E	I	R_a	R_t	E	L
1	80	.0288	189	2967.8	92.6	11.9
2	77	.0277	120	2898.8	85.5	10
3	80	.0288	261	3039.8	92.0	9.24
4	80	.0288	238	3016.8	95.5	13.12
5	68	.0244	251	3029.8	94.1	22.65
6	83	.0296	258	3036.8	96.4	10.87
7	81	.0292	163	2941.3	92.0	11.03
8	59	.0222	222	3002.8	72.5	12.1
9	73	.0261	218	2996.8	91.8	17.6
10	67	.0239	218	2996.8	74.0	7.58

E_v = Voltage reading on 0-150 scale of Weston Voltmeter

R_v = Resistance of voltmeter coil = 2778.8 ohms

I = Current in circuit.

R_a = Resistance of armature winding.

R = Total resistance in circuit. $R_t = R_a + R_v$

E_e = Voltage reading on electrostatic voltmeter

L = Coefficient of self induction in henrys obtained from equation.

$$I = \frac{E_e}{\sqrt{R_t^2 + (2\pi f L)^2}}$$

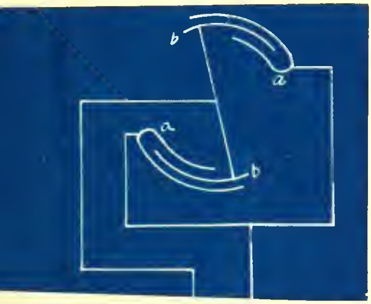
f = Frequency 16.2/3 cycles per second

As seen from these results the inductance of the armature is very high. Rather a large amount of current generated must be used to overcome the inductance of the generator itself, the rest is sent over the line.

Calibration of the Electrostatic Voltmeter.

For use in determining true E.M.F.

The Ayrton and Mathers Electrostatic voltmeter was used in determining the true effective and instantaneous E.M.Fs. of the magneto generators. This voltmeter is shown diagramatically in Figure # 1.



a,a are two stationary thin aluminum plates shaped as shown as shown in figure; these are connected electrically and form one terminal of the voltmeter. b,b are moveable plates to which a mirror is attached, forming the needle of the instrument. The forces operating on the instrument are due to the attraction and repulsion between static charges. This instrument can be used for both direct and alternating current it has no self -induction, and takes no appreciable current, even on an alternating current circuit, on account of its small capacity. The readings of the voltmeter are taken by the deflection of the mirror on a fixed scale marked off in millimeters, the scale is attached to a telescope. In order to know the value of the E.M.F. the instrument must be calibrated.

The apparatus for calibrating the electrostatic voltmeter was connected as shown in scheme, Figure # 2.

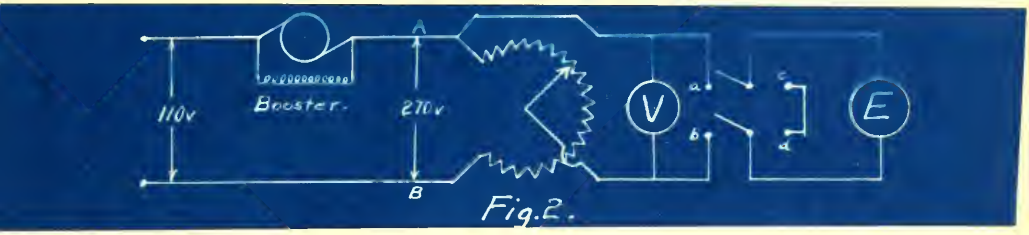


Fig.2.

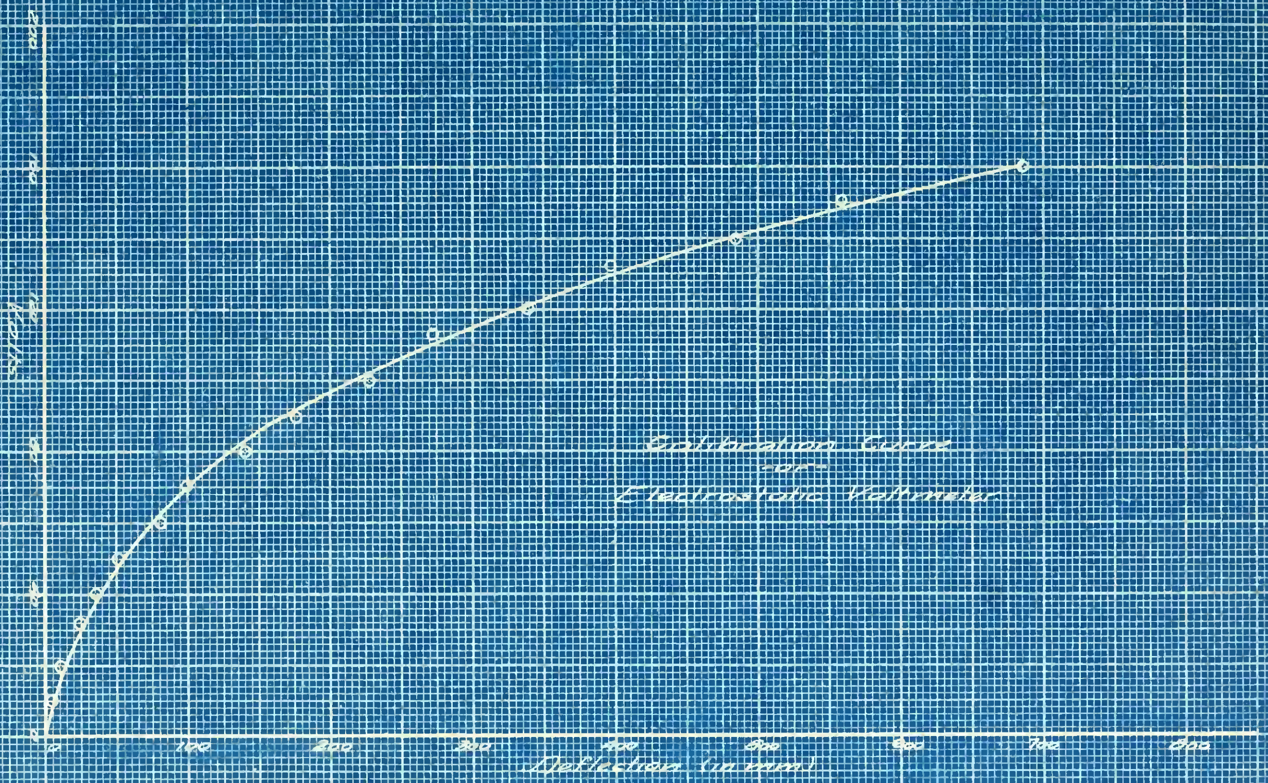
Direct current was used for calibration, since only 110 volts were available a booster was used, as shown, this was adjusted so as to give a voltage of about 270 volts across AB. V is a Weston 0- to 300 voltmeter, and E is the electrostatic voltmeter. By means of the variable potential reheostat, R, any voltage, from 0 to the maximum, could be obtained. The scale on the telescope was at a distance of one meter from the mirror E. The Zero reading of E was taken with the switch on the points cd, therefore with E short circuited or discharged. The switch was then reversed to ab, and the voltage was steadily increased by ten volt increments to the maximum point and immediately after it was steadily decreased back to zero. The deflections of the electrostatic voltmeter, in milli-meters were taken at each interval.

From the two sets of readings an average was taken see Table # 3. Anda curve plotted having deflections in mm. as abscissae, and volts for ordinates. This calibration curve is shown in the accompanying blueprint.

TABLE #3

Calibration of electrostatic voltmeter

Voltage	Deflection in m.m. Ascending	Descending	Average
0	0	0	0
10	3	5	4
20	9	12	10.5
30	20	23	21.5
40	34	38	36
50	55	59	57
60	79	84	81.5
70	108	112	110
80	138	146	140
90	179	189	184
100	224	233	228.5
110	277	284	280.5
120	335	344	339.5
130	403	414	405.5
140	485	494	489.5
150	573	585	579
160	680	692	686
166	760	760	760



EUGENE DIETZGEN CO., CHICAGO.

Production of the E.M.F.Wave.

The electro-motive force at any instant is proportional to the rate at which a conductor cuts the lines of force. As the conductor moves around from point to point the rate of cutting changes.

Consider one conductor starting at A moving around in the field produced by the two poles,N,and S of a magneto generator, as shown in figure no.3.

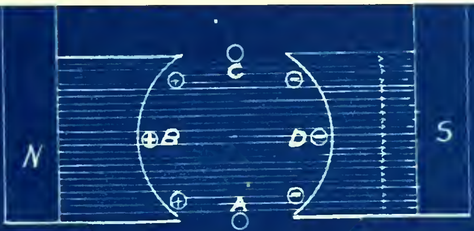


Fig.3.

Allow the armature to rotate at a constant speed in the direction indicated by the arrow,and the conductors occupying the eight successive position as shown.

In passing the position A,The conductor is moving paralell to the lines of force and hence does not cut them;the rate of cutting is therefore Zero,and hence the electromotive force at this instant is Zero.As the conductor (towards) B,it is cutting the lines of force and an E.M.F. is induced.At B it is moving at right angles to the lines of force,cutting them at its maximum rate,hence the E.M.F.induced reaches its maximum value.As it moves around,the E.M.F. decreases and at C it is again Zero.

In this one half revolution the E.M.F. generated is in the positive direction.In the other half revolution a maximum E.M.F. is produced at D,which decreases and comes back to Zero at A. In this case,howevere,the direction of E.M.F. is reversed because the lines of force are cut in a direction opposite to that in which they were cut before.

The values of the E.M.Fs at each position are shown graphically in Figure # 4.

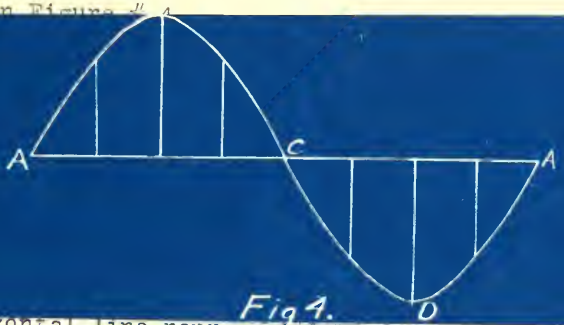


Fig.4.

The horizontal line represents the interval in degrees and the vertical lines the values of the E.M.Fs.The curve shows at a glance the complete change that takes place during one cycle or revolution of the armature.This is the theoretical form of the E.M.F. wave produced by the generator.

The no load wave of each generator was obtained by determining the instantaneous values of the E.M.Fs. corresponding to definite positions of the conductors with respect to the poles of the generator.The general method of carrying out this operation is indicated by the scheme Figure # 5.

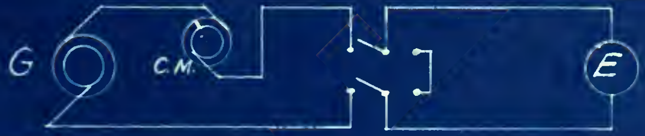


Fig.5.

G, is the generator, C.M. is the contact maker and E is an electrostatic voltmeter.The contact maker was rigidly connected to the armature by means of a Hook's coupling.The armature and contact maker were rotated by a 1-4 H.P.motor.The speed of the generator was kept constant at one thousand R.P.M. throughout the test.The general plan of this test is to adjust the contact maker so that it will complete the circuit at the instant the conductors of the armature are in the desired position . The rapidity of rotation of the armature causes a rapid succession of such contacts resulting in the production of a series of impulses of equal E.M.F.This instantaneous E.M.F. produced at the chosen position of the conductors is measured by the electrostatic voltmeter.

When the armature is in position as shown by A,Figure # 6. All of the lines of force thread through the armature core between the coils and no E.M.F. is generated .

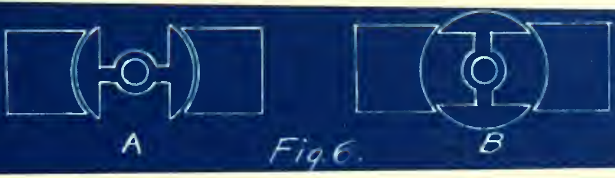


Fig.6.

At the position B The conductors have cut across all of the lines of force and the maximum E.M.F. is generated .

The armature was set in the position shown at A where the E.M.F. is Zero.The dial of the contact maker was clamped at Zero and the arm carrying the contact brush was adjusted so that the brush made contact thus completing the circuit. This arrangement makes the Zero of the contact maker coincide with the Zero point on the E.M.F. wave.

The contact maker was moved forward every ten degrees, thus obtaining step by step the instantaneous E.M.F.corresponding to each position of the conductors,for a complete cycle.

The deflections of the electrostatic voltmeter were read in milli-meters with a telescope and scale.The correspoding voltage was then read from the calibration curve of the voltmeter.The deflections of the voltmeter,point by point , are recorded in table # 4,and the values of the instantaneous E.M.F.,as obtained from the calibration curve are shown in Table # 5.Curves were plotted,using the successive instantaneous values of the E.M.F. as ordinates,the abscissas representing degrees.The curves are called the"No load E.M.F. " Waves", and are shown in the following blueprint.,for each generator.

The shape of the E.M.F Waves of each generator are practically the same .But they are all entirely different from the shape of the theoretical E.M.F.Wave as shown in figure # 4. The Waves are in each case distorted,since in the manufacture and operation of generators,it is impossible to realize all of the ideal conditions necessary for the production of the sine wave.The shape of the armature cheek has the greatest effect upon the distortion of the E.M.F. waves.In the generators under test the armature cheeks were rather wide,overlapping the interval between the pole pieces,thus preventing a rapid rise in the E.M.Fs at the beginning and end of each alternation.

Table #4A

Zero Reading 770

Gen-------	#I	#2	#3	#4	#5	#6	#7	#8	#9	#IO
Degrees	Deflections.									
0	767	758	767	767	766	763	762	760	746	759
IO	765	757	763	764	764	760	759	759	754	758
20	764	756	760	762	762	759	757	759	745	757
30	764	748	757	760	759	758	752	759	733755	
40	762	742	752	757	753	750	745	758	727	753
50	758	738	743	75I	745	747	7I3	756	709	745
60	749	688	7IO	742	723	730	645	750	490	738
70	723	480	370	714	615	680	653	735	501	735
80	470	510	420	585	450	430	660	673	640	563
90	310	530	420	250	250	410	500	535	240	440
100	540	732	744	510	700	670	720	560	727	670
110	665	744	752	649	730	71o	737	680	732	732
120	737	745	755	730	743	737	746	720	740	743
130	750	750	758	747	752	743	753	738	737	749
140	758	752	759	754	757	749	756	746	746	752
150	759	753	760	759	760	753	759	757	748	755
160	763	754	763	760	762	755	761	755	738	756
170	766	756	764	762	764	756	762	757	742	757
180	767	756	763	765	763	758	761	758	748	757

TABLE # 4B

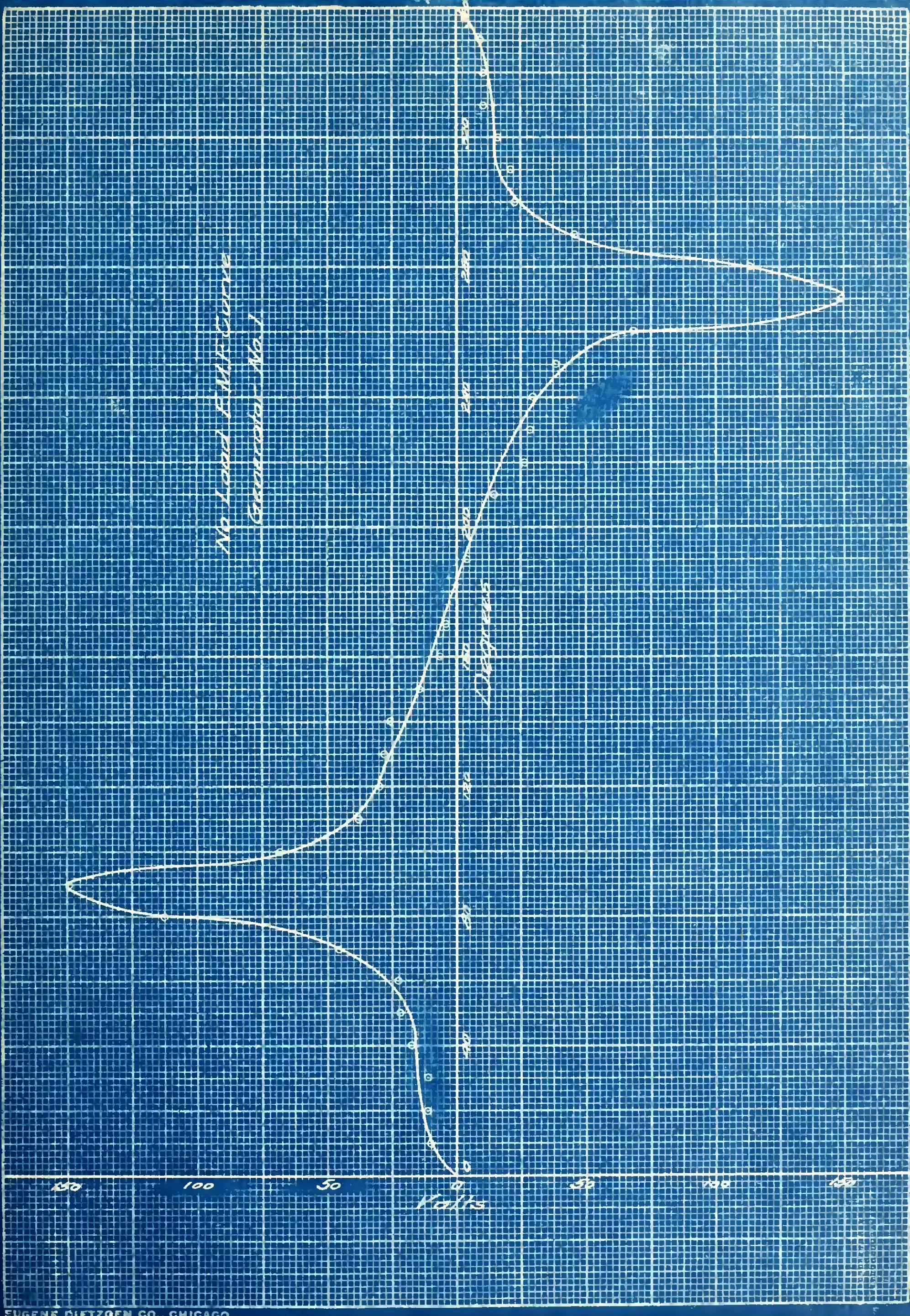
No Load E.M.F.

Generator	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Degrees	Deflections in mm.									
0	0	0	0	0	0	0	0	0	0	0
10	5	13	7	6	6	7	7	10	24	11
20	6	14	10	8	8	10	10	11	25	12
30	6	22	13	10	11	11	12	11	25	13
40	8	28	17	13	17	12	17	11	25	13
50	12	32	27	19	25	20	24	12	43	25
60	21	82	60	28	47	23	66	14	61	32
70	47	130	130	46	153	40	168	19	280	227
80	300	162	280	185	370	90	190	97	365	330
90	560	290	400	520	520	360	269	235	530	360
100	105	37	62	260	190	60	99	90	130	100
110	33	26	26	176	70	33	49	50	62	27
120	20	25	18	40	40	27	32	22	43	21
130	18	20	15	23	27	21	23	24	38	18
140	17	18	12	16	18	17	17	17	36	15
150	7	17	11	11	13	15	13	15	33	14
160	4	16	10	10	10	14	10	13	24	13
170	3	14	7	8	8	12	8	12	22	13
180	3	14	6	5	6	14	7	11	22	13

TABLE #5

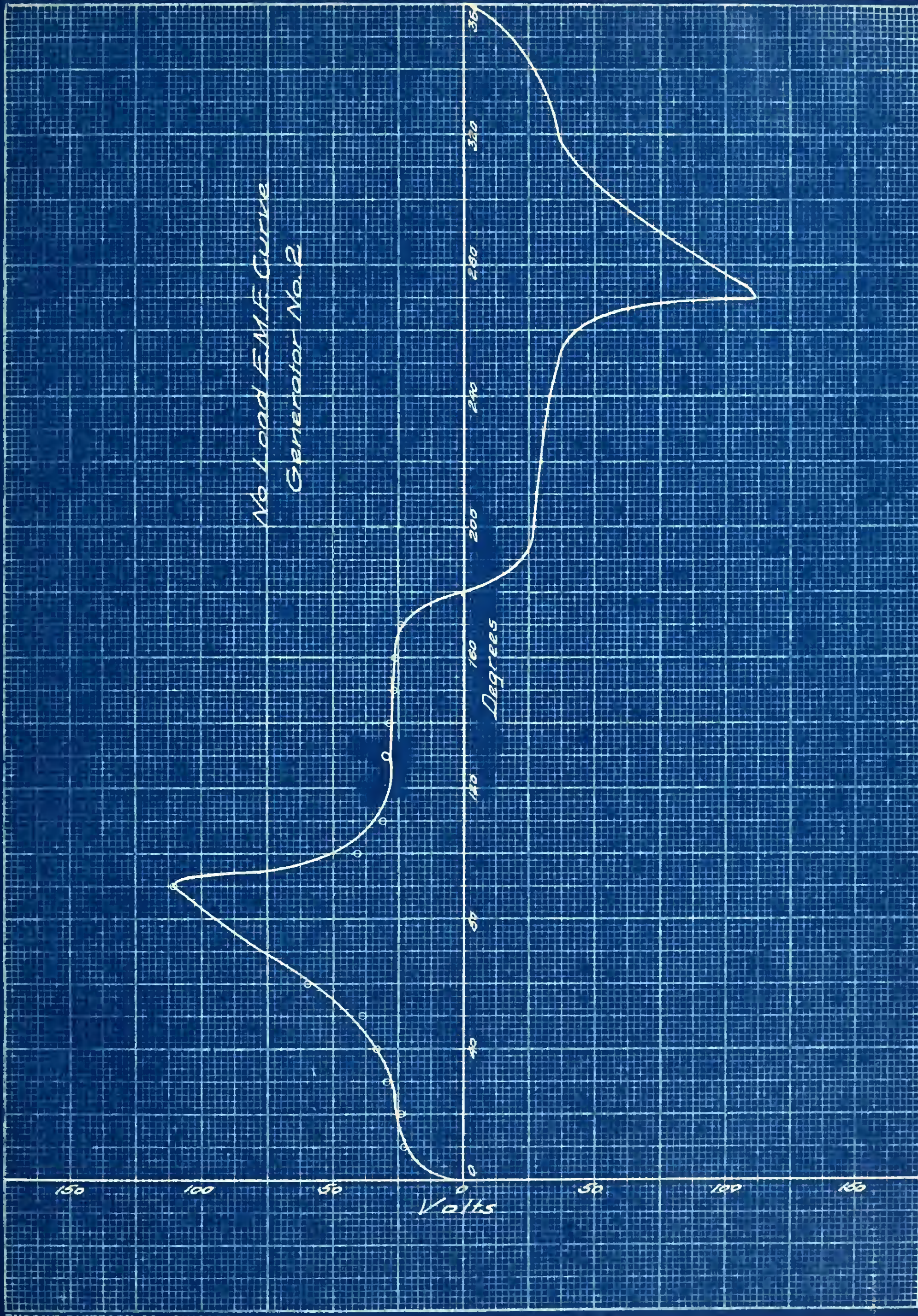
No load E.M.F.

Generator	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Degrees			Voltage from calibration curve							
0	0	0	0	0	0	0	0	0	0	0
10	10	23	15	11	11	15	15	10	24	21
20	11	24	20	17	17	20	20	21	42	22
30	11	32	23	20	21	21	22	21	42	23
40	17	36	28	23	28	22	27	21	41	26
50	22	37	36	30	35	31	34	22	44	35
60	23	60	52	36	47	33	54	24	52	38
70	46	80	80	45	84	43	87	30	110	40
80	113	95	110	91	120	64	92	66	122	101
90	149	111	129	144	144	122	108	101	148	118
100	68	41	52	106	92	52	67	64	77	67
110	28	36	36	90	65	28	46	47	52	37
120	30	35	29	43	43	36	39	41	44	36
130	28	30	25	33	36	31	33	34	43	26
140	26	28	22	26	29	27	28	30	38	29
150	14	27	21	21	23	26	23	26	39	26
160	6	26	20	20	24	20	20	23	34	24
170	4	24	14	14	17	22	17	22	32	23
180	4	24	11	5	11	24	15	21	32	23

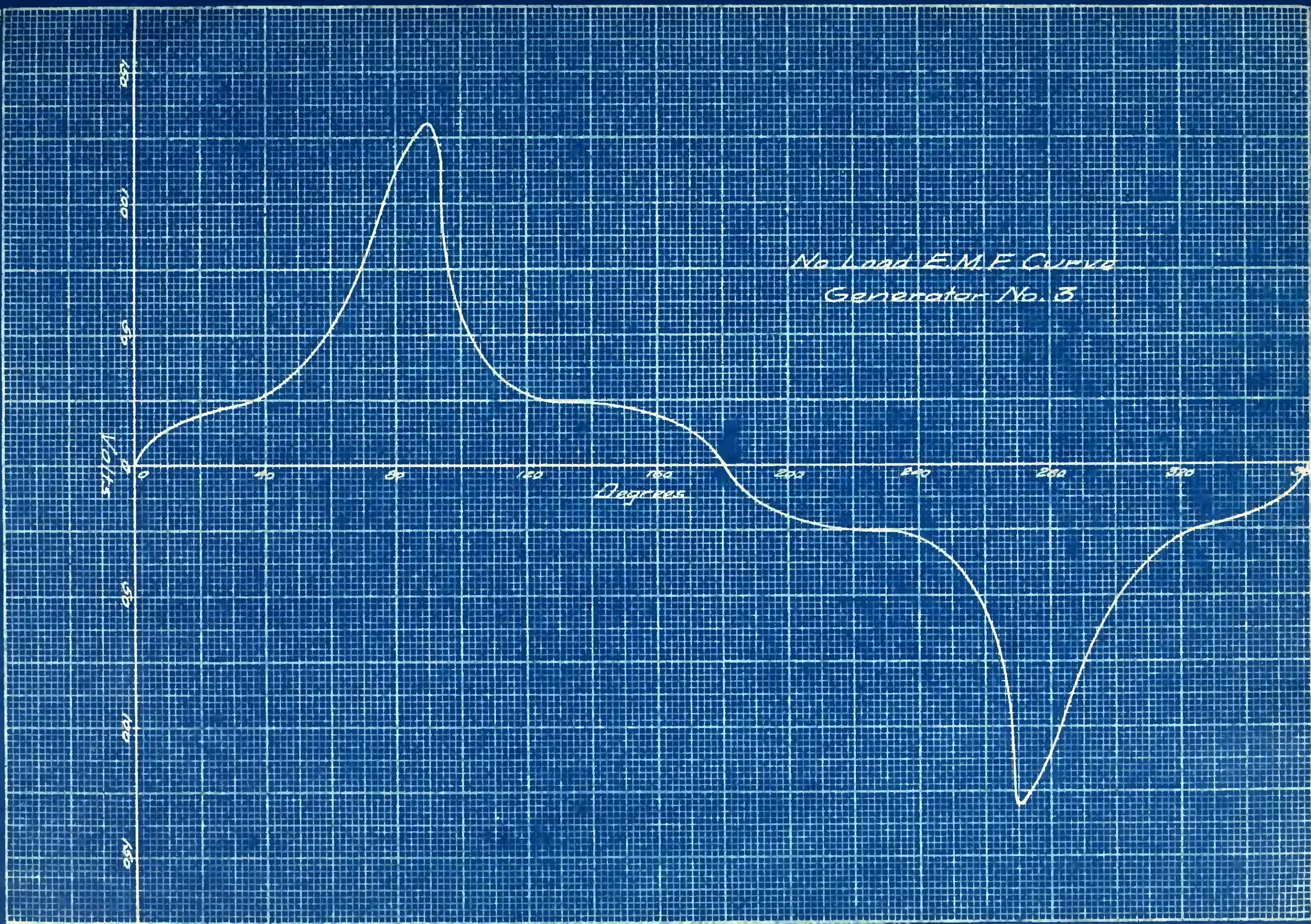


No Load E.M.F. Curve
Generator No. 1

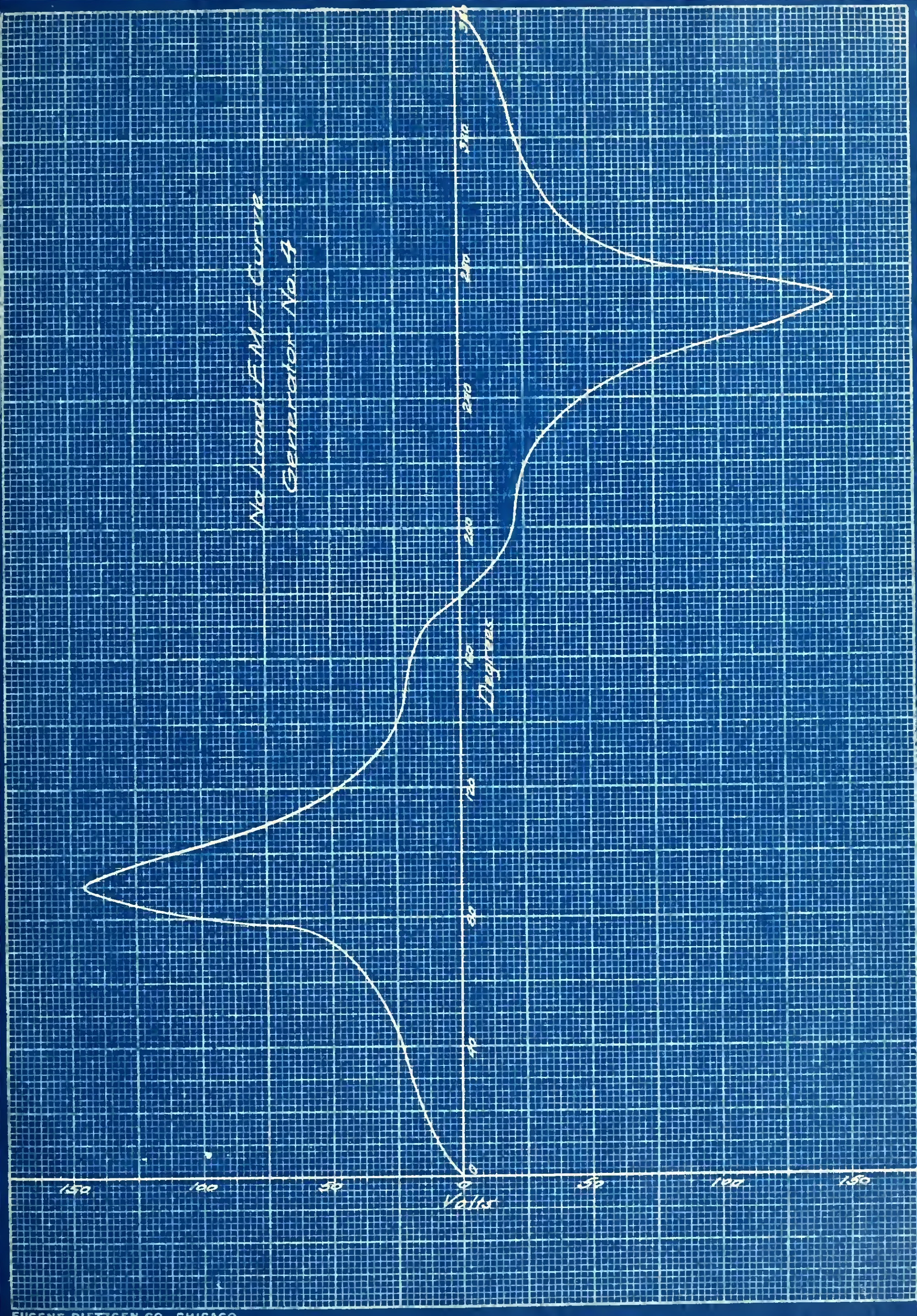
EUGENE DIETZGEN CO., CHICAGO.



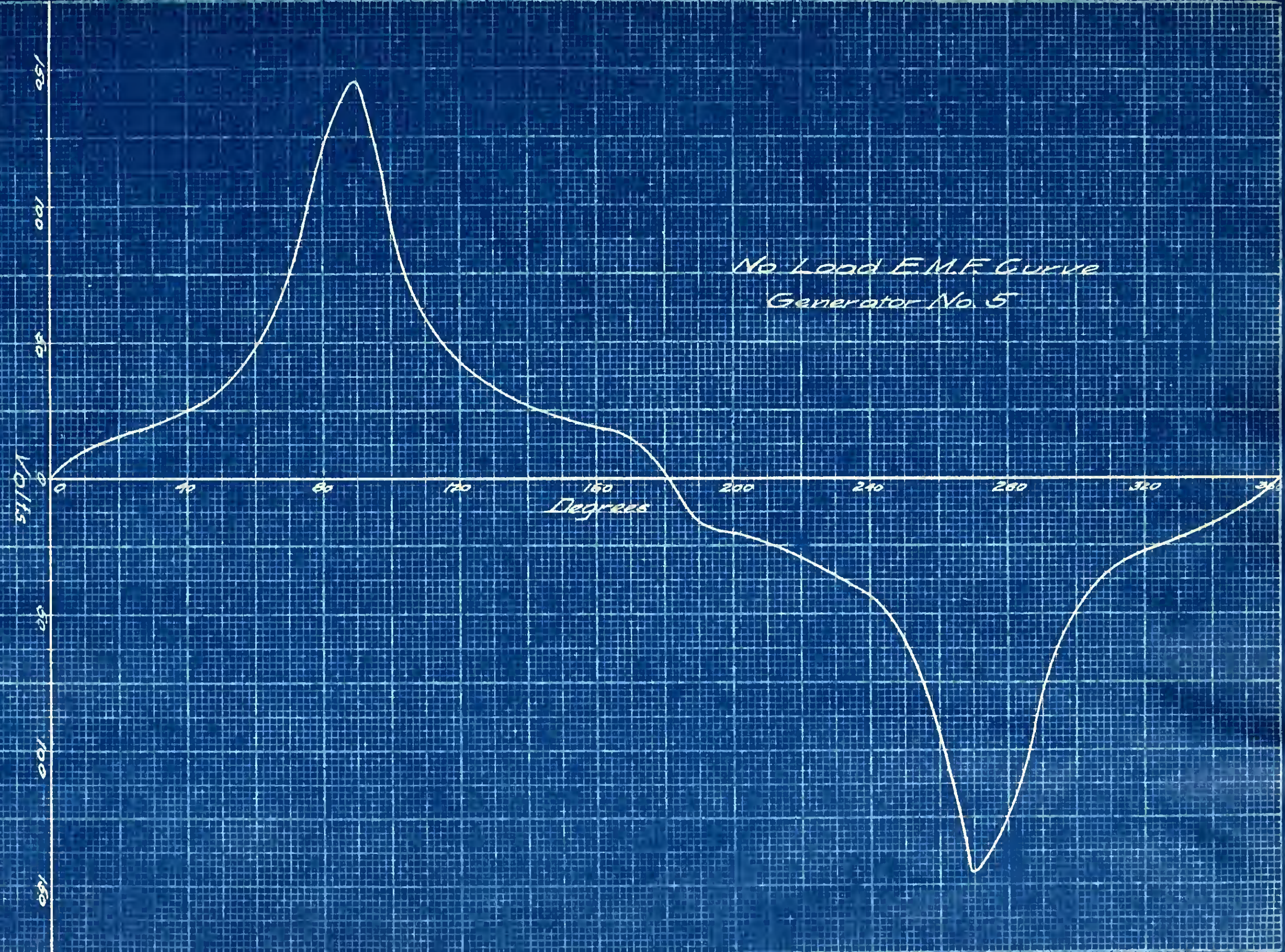
EUGENE DIETZGEN CO., CHICAGO.



EUGENE DIETZGEN CO., CHICAGO.

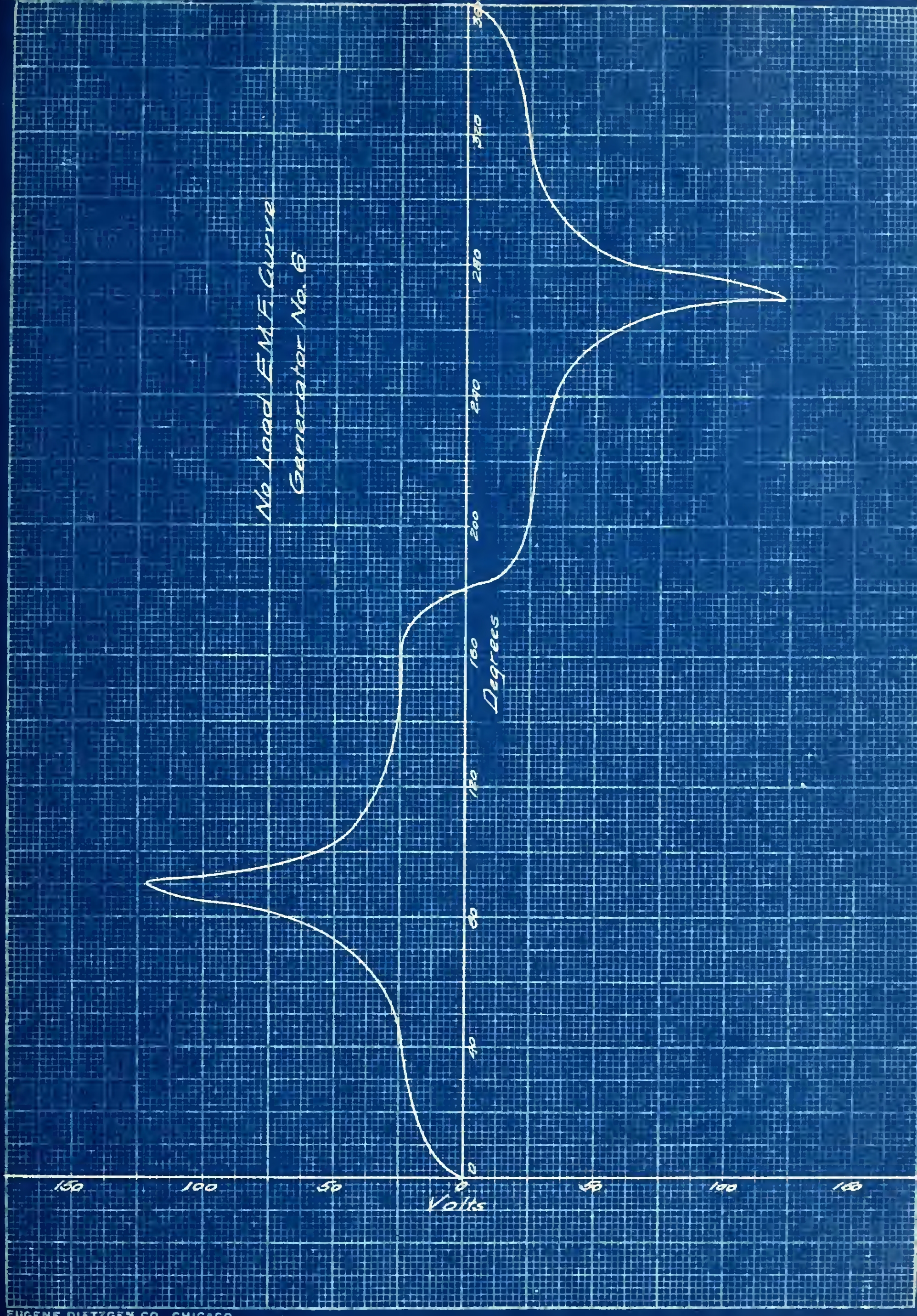


EUGENE DIETZGEN CO., CHICAGO.

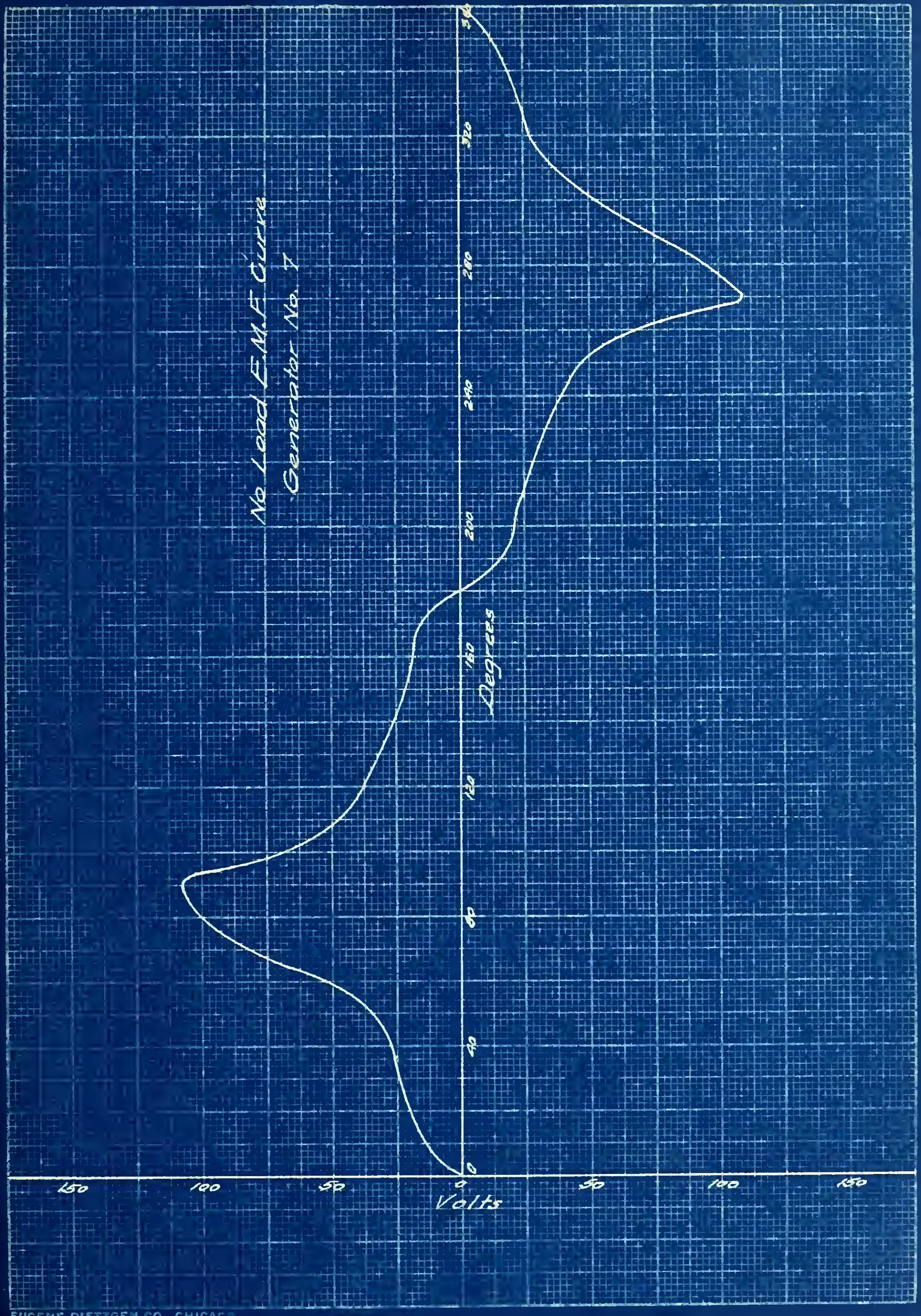


No Load E.M.F. Curve
Generator No. 5

EUGENE DIETZGEN CO., CHICAGO.

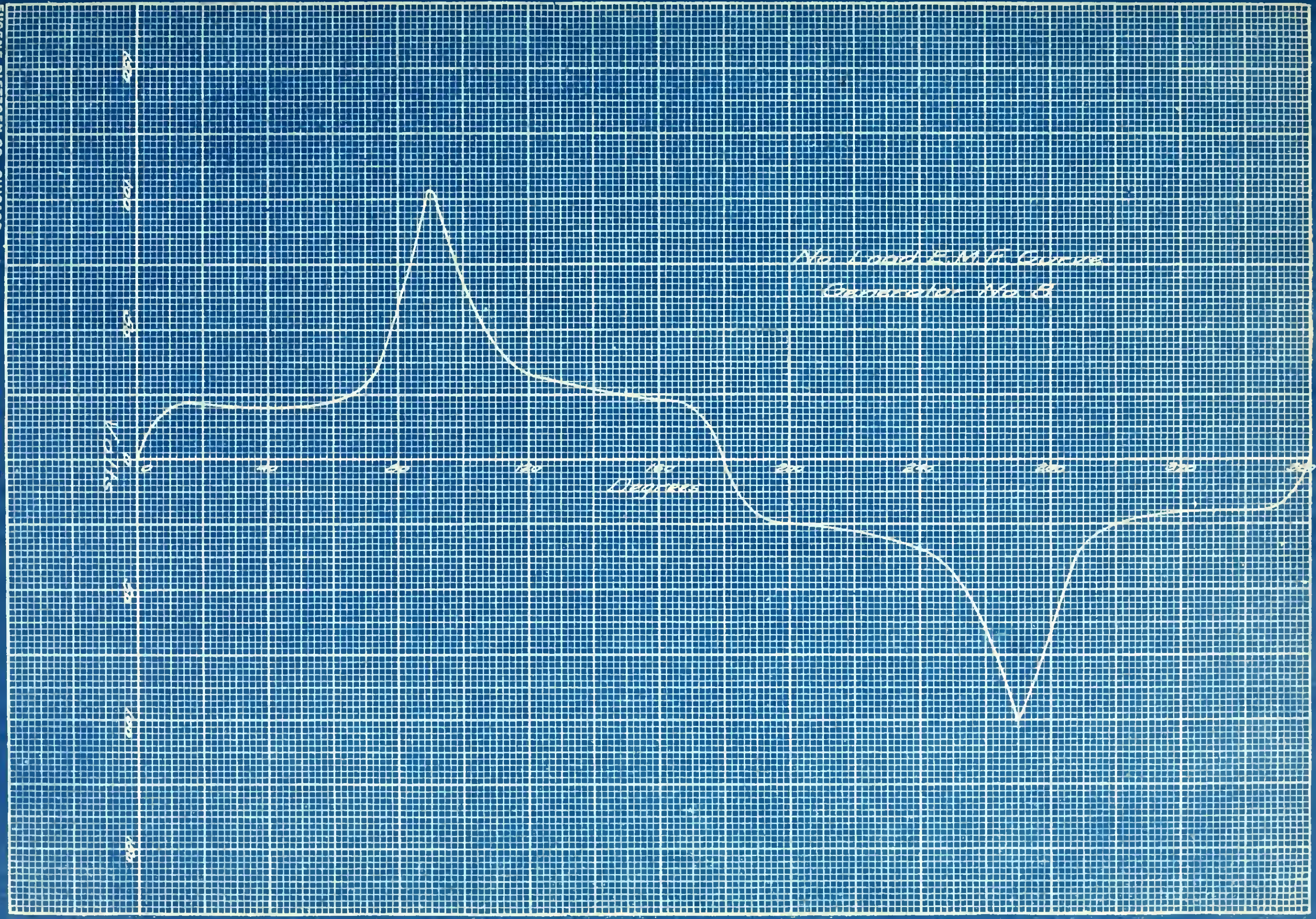


EUGENE DIETZGEN CO., CHICAGO.

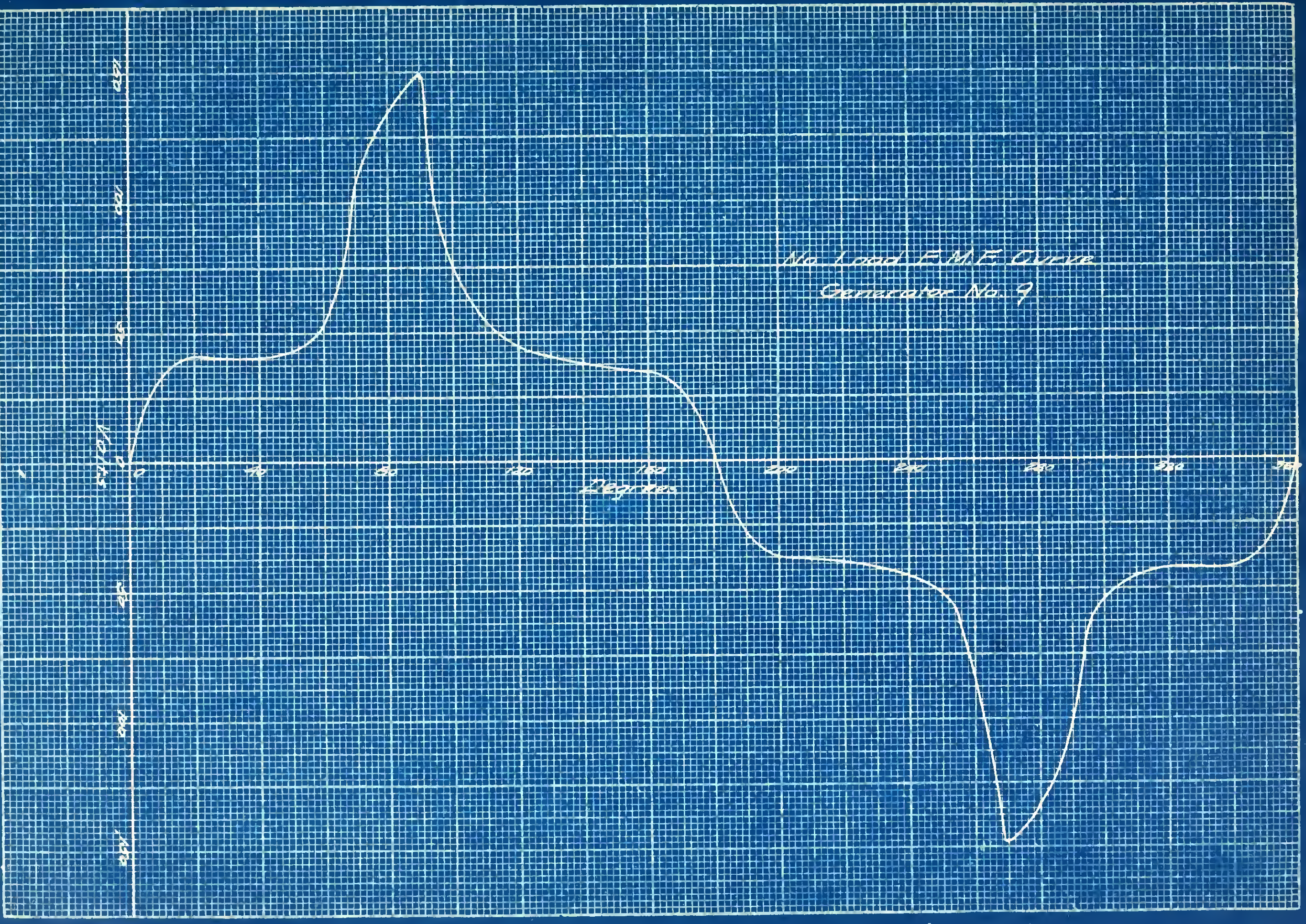


No Load E.M.F. Curve
Generator No. 7

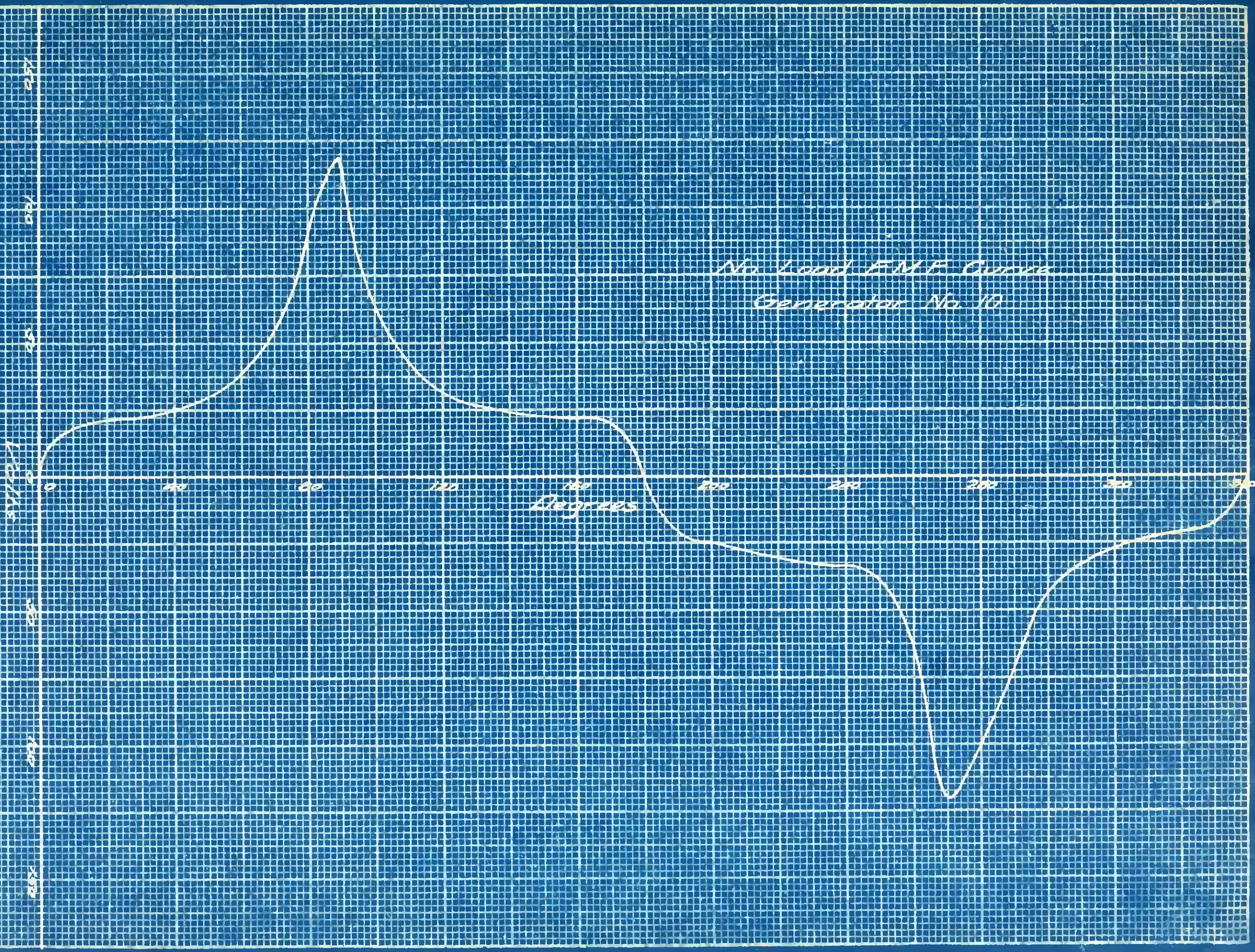
EUGENE DIETZGEN CO., CHICAGO.



EUGENE DIETZGEN CO., CHICAGO.



EUGENE DIETZGEN CO., CHICAGO.



EUGENE DIETZGEN CO., CHICAGO.

Starting in the position of Zero E.M.F. the rise in voltage is very slow for the first sixty degrees of rotation; above that point the voltage rises very rapidly, reaching its maximum value at ninety degrees. The distortion of the waves is also due to the presence of higher harmonics. This is explained in a later paragraph.

Effect of Non-Inductive resistance loads, Inductive, and Capacity Loads on the E.M.F. of the Magneto Generators.

Consider a non inductive resistance load in the circuit. The current being in phase with the E.M.F. In Figure # 7. Consider the coil to be in position OC, The current will then be proportional to the projection of OC on OB, that is Oc.

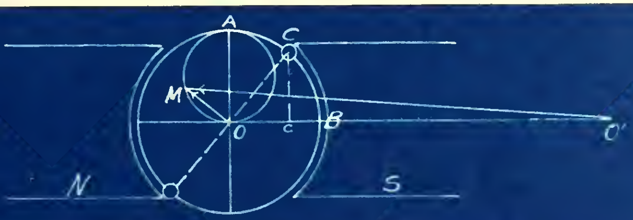


Fig. 7.

Now the magnetizing force of this current is in quaditure with the current and therefore will have the position OM. If Oc is taken to be porportional to the magnetizing force of the coil in the position OC, it may be shown that the locus of the magneto motive force is the circle OMA. Let OO' represent the magneto motive force of the field magnets, using the same scale for which OM represents magneto motive force of the coil. $O'M$ then represents the resultant magneto motive force in magnitude and direction.

The average value of the magnetic force is seen to be above the same;the effect of the coil being to slightly distort the E.M.F.or current wave.

Consider an inductive load in the circuit,producing a lagging current ,which reaches its maximum value when the coil is in the position OB Figure # 8.

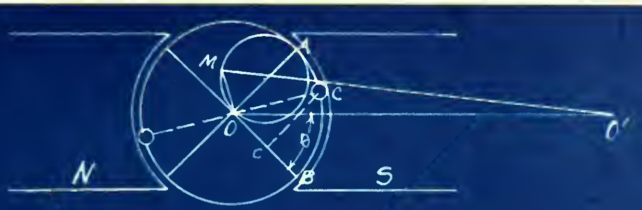


Fig. 8.

The locus of the magneto motive force is now the circle OMA. The circle in the former figure has been shifted through an angle equal to the angle of lag . The average value of the magneto motive force OM is now reduced ,and therefore, the E.M.F. generated is decreased.

For a condenser load the current is leading and we get the effect shown in figure # 9.

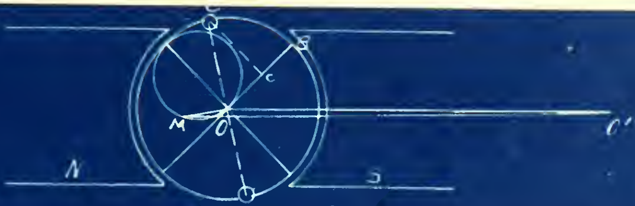


Fig. 9.

The locus of the magneto motive force is again the circle OMA. In this case the circle has been given an angle of lead. The average value of the magneto motive force,OM is now increased,and the E.M.F. generated is therefore increased.

The E.M.Fs. of each generator were measured for various loads, with a 150 volt scale of the Weston voltmeter. Although these readings do not give the correct voltages yet they show the comparison for the various loads and generators. The loads taken were, first, a non-inductive Resistance consisting of three 16 cp.lamps having a cold resistance of 1192 ohms; second, inductive loads consisting of 1600 ohm ringers, placed in paralell. These are designated by the letter B, the subscript denoting the number in circuit; third, condenser loads, consisting of 4 two micro-farad condensers, these are designated by the letter C; fourth, a combination of ringers and condensers. These various loads were easily placed in circuit by means of an arrangement of swicthes, jacks, and a two conductor plug as shown in blue print Figure # 12. The values of the E.M.F. are shown in Table # 6.

According to the proceeding discussion it is seen that when an inductive load is placed in circuit the voltage is greatly reduced. With a ringer and condenser together in the circuit, the E.M.F. is increased, while for a condenser alone in circuit the E.M.F. is even greater than the no load voltage of the generator. By increasing the number of ringers or condensers in the circuit, there is not much of a variation produced in the E.M.F.

TABLE #6

Effective E.M.F. for each load measured with Weston voltmeter

Generaror	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
No Load	80	77	80	80	68	82/5	81	59	73	66.5
R	52	57	80	53	68	82	81	40	73	66
B_1	35	42	36	36	33	38	38	26	31	34
B_2	34	41	35	36	32	37	37	25	30	33
B_3	33	40	34	35	31	36	36	24	29	32
B_4	32	40	33	34	30	35	35	24	28	31
C_1	91	86	89	87	75	91	87	64	81	75
C_2	88	87	85	86	74	90	87	65	77	75
C_3	88	85	82	86	72	88	90	65	79	72
C_4	92	82	83	87	73	89	93	66	82	71
B_1C_1	78	75	75	78	66	81	81	60	71	64
B_2C_2	71	70	68	71	60	73	75	52	64	60
B_3C_3	66	67	62	65	55	67	68	47	58	56
B_4C_4	61	64	58	61	52	62	64	44	54	53
B_1C_2	80	75	74	79	66	80	84	59	73	63
B_1C_3	82	74	73	78	66	79	86	57	72	63
B_1C_4	79	73	69	74	62	76	84	53	68	61

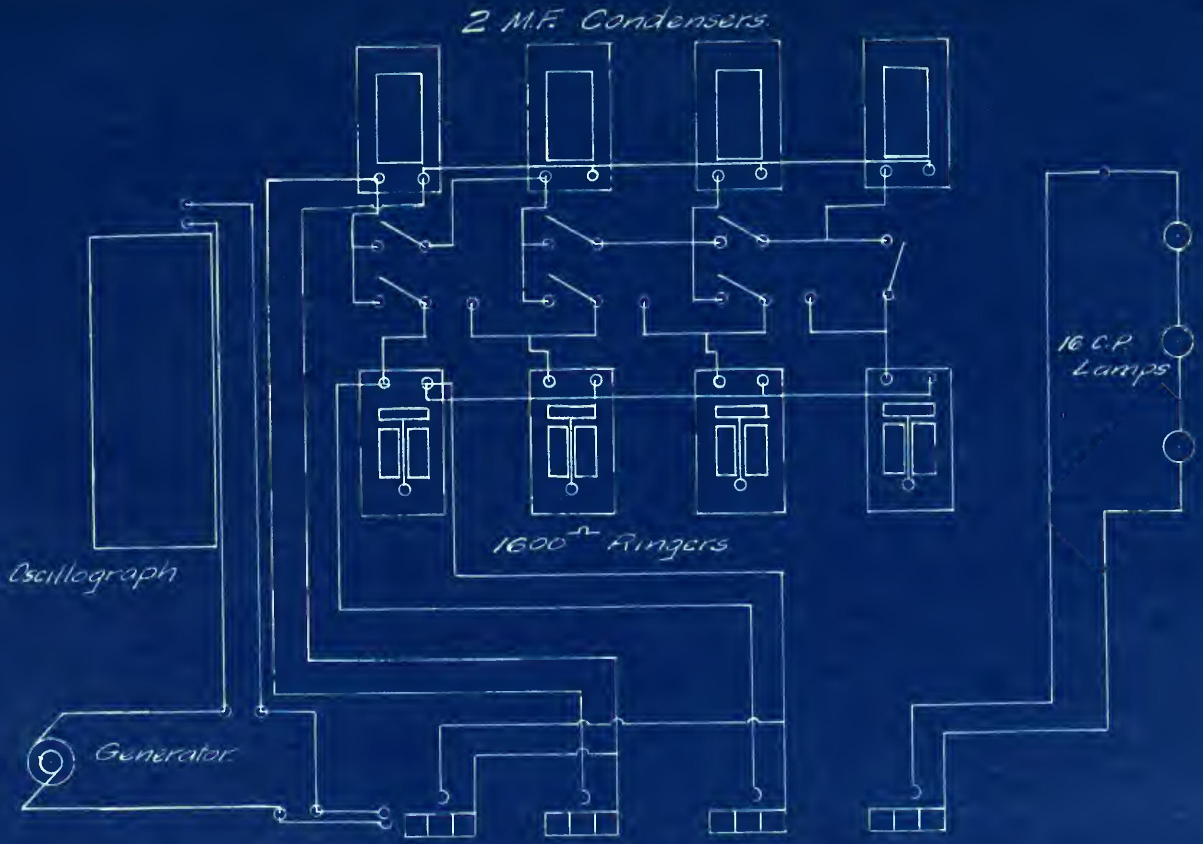


Fig. 12
Wiring diagram showing arrangement for placing various loads in generator circuit.

Oscillographic study Of Current Waves.

The General Electric Oscillograph was used. The apparatus consists of an electro magnetic galvanometer with moving mirror of extremely high period and suitibly damped, a box in which the galvanometer with the necessary lenses, mirrors, prisms, and shutter for controlling light are placed. An arc light furnished the beam of light for the galvanometer mirrors. The moving elements or vibrators are single loops of flat wire held in tension by a small spiral spring. A small mirror is attached to the strips, the vibrators are slid in the chambers between the poles of the magnets.

The waves can either bephotographed or traced. For the later method, the one used there is provided a tracing table, on which a piece of transparent paper is placed and a tracing m made of the observed wave. In this case the wave must be stationary, otherwise it would be impossible to trace it. The waves can be made stionary by either electrical or mechanical means. For large alternators a small synchronous motor is used, which is driven by the same machine that furnishes power to the circuit under investigation. This motor causes a long narrow mirror to vibrate. The beam of light from the vibrating mirrors strike this synchronous mirror and moves back and forth over the glass on the tracing table, giving the length of the wave, the rotary movement. of the vibrator gives the amplitude, the combination of the two gives the wave.

The current generated by the Magneto generator is too small to drive a synchronous motor hence mechanical means were adopted. A two inch gear was fastened to the armature shaft of the synchronous motor, and was driven by a four inch idler, which in turn was driven by a one inch gear. The one inch gear was fastened to the shaft by a rigid connection, which drove the armature of the magneto generator. By this arrangement the armature of the motor was driven at exactly half the speed of the generator. This produced a stationary wave consisting of only one cycle.

A complete detailed drawing of the apparatus used is shown in figure # 10 and # 11.

The magneto generator was placed on an adjustable platform, and directly coupled to the main driving shaft as shown in figure # 10. A 1/4 H.P. motor was used for driving the generator the speed of which was kept constant at one thousand R.P.M. The speed was regulated by means of rheostats in the armature and field circuits of the motor. Current waves were taken for various loads as stated before. Figure # 12 shows the switching arrangement used for placing the various loads in circuit.

On account of the odd shape of the iron of the generator armature, the permeability of the magnetic circuit is not uniform throughout a complete revolution. The current wave is therefore distorted and consists of a combination of a sine wave with some of its higher harmonics.

c; i.e.

es go

n

ng current

of the

e time

the

$) + ----$

$, \theta_3,$ the

the

nda-

tc.

s

maybe

- - -

phase

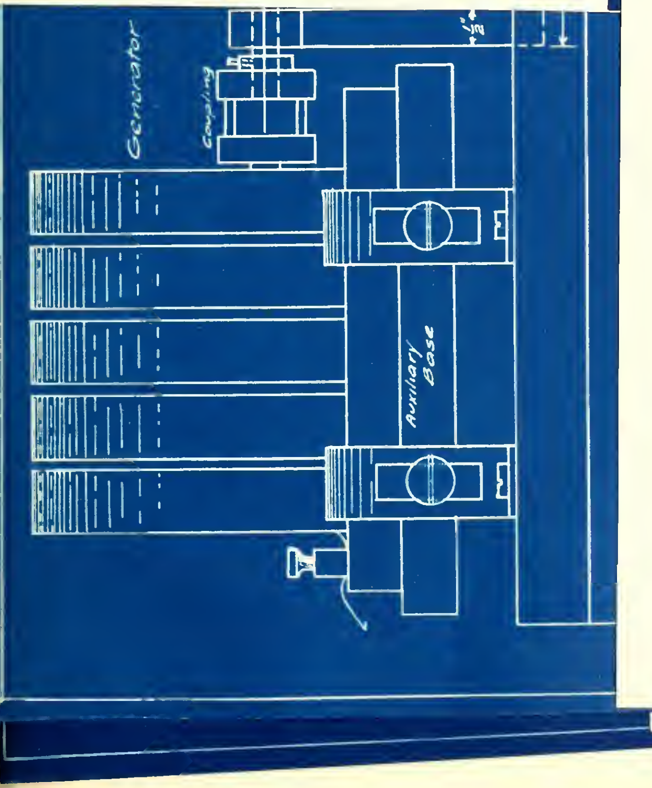
a non-

aph,

shown in

trical.

before



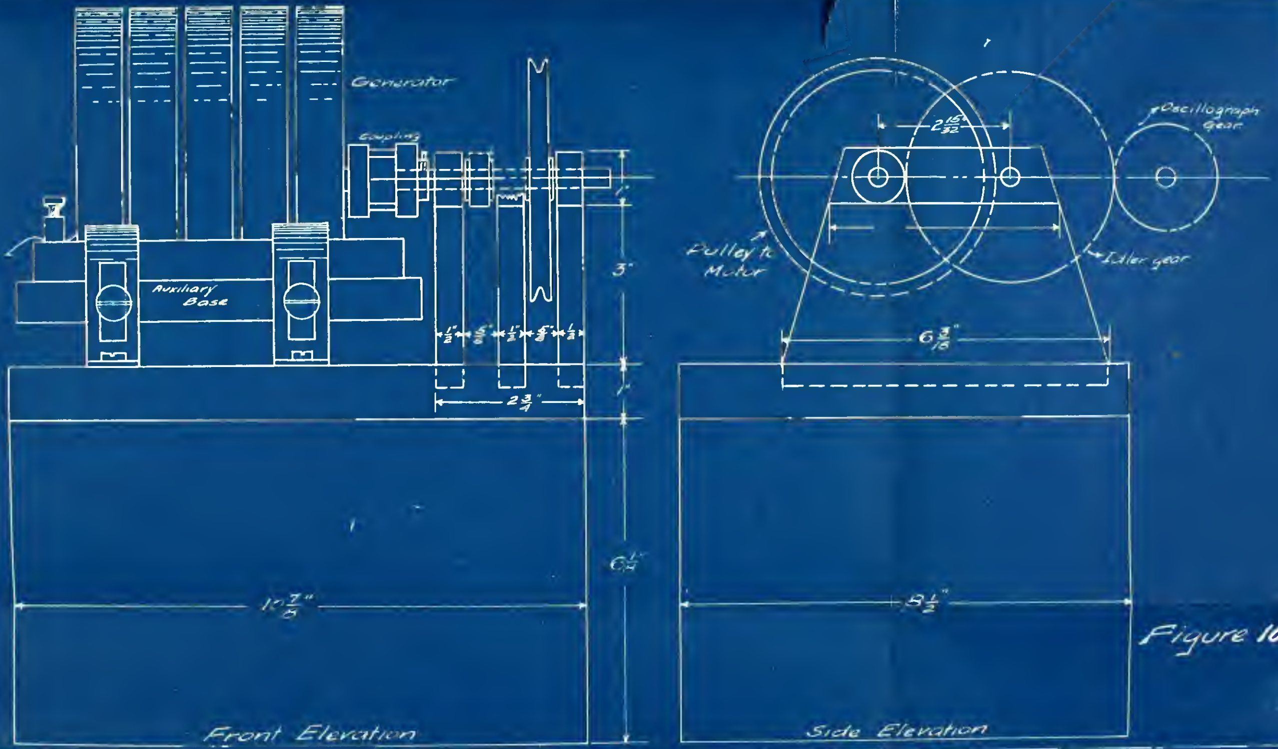

Generator
Coupling
Auxiliary Base
1"
3"
1"
6½"
½"
⅝"
½"
⅝"
½"
2¾"
10⅞"
Front Elevation
2 15/32"
Oscillograph Gear
Pulley to Motor
Idler gear
6 3/16"
8½"
Side Elevation

Figure 10

All alternati

c; i.e.

es go

n

ng current

n of the

e time

the

) + - - - -

, θ_3, the

the

unda-

etc.

es

maybe

- - -

phase

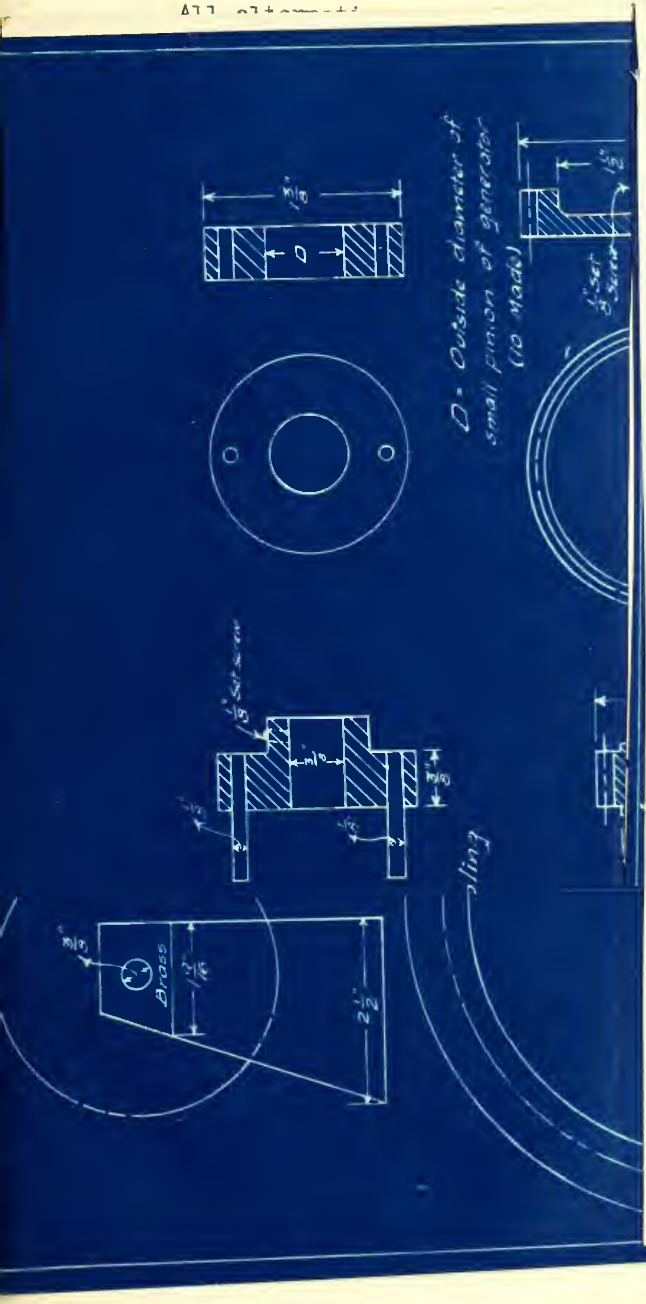
a non-

aph,

shown in

trical.

before



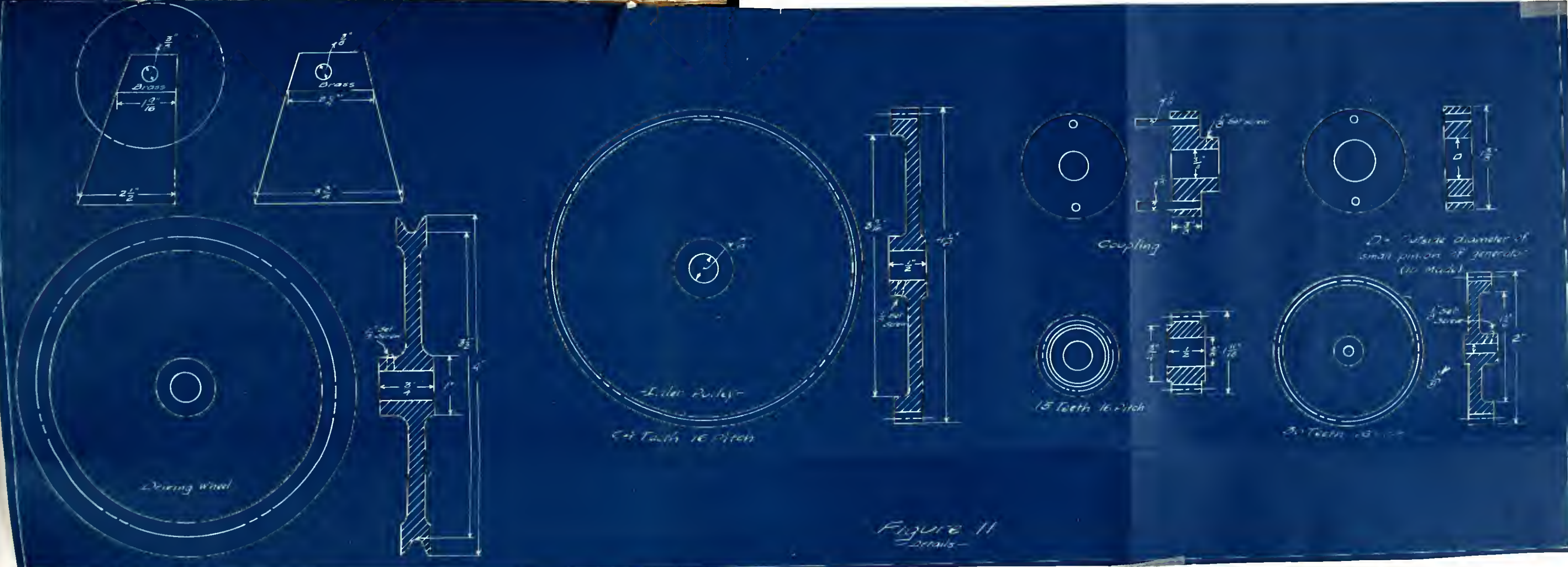


Figure 11
—Details—

All alternating currents and E.M.F.s are periodic; i.e. there is a certain periodic time in which their values go through a complete cycle of changes, and that in each succeeding time this cycle is repeated. Any alternating current or E.M.F. may be represented by some periodic function of the time.

By Fourier'stheorem any periodic function of the time of frequency f may be represented by an expression of the form

$$a_1 \sin(\omega t - \theta_1) + a_2 \sin(\omega t \cdot 2 - \theta_2) + a_3 \sin(3\omega t - \theta_3) + ---$$

where $\omega = 2\pi f$, a_1 $a_2 a_3$ are the amplitudes and $\theta_1, \theta_2, \theta_3$, the phases.

The frequency of the first term is f and those of the other terms are $2f$, $3f$,. The first term is called the fundamental, while the others are called the first, second, etc. harmonics. The even harmonics are absent from the curves representing alternating currents and E.M.Fs, so these maybe represented by the expression

$$a_1 \sin(\omega t - \theta_1) + a_3 \sin(3\omega t - \theta_3) + a_5 \sin(5\omega t - \theta_5) + ---$$

Figure # 13 shows the curve, A, compounded of the fundamental and the second harmonic~~s~~ .In this case the phase angle, θ_1 is Zero, and A represents the current wave for a non-inductive load. The curve, R, obtained with the oscillograph, for non-inductive load ~~and~~ is more distorted than that shown in Figure #13 which is symmetrical. The curve R is not symmetrical. Being steeper on one side and reading the maximum value before 90 degrees.

EUGENE DIETZGEN CO., CHICAGO.

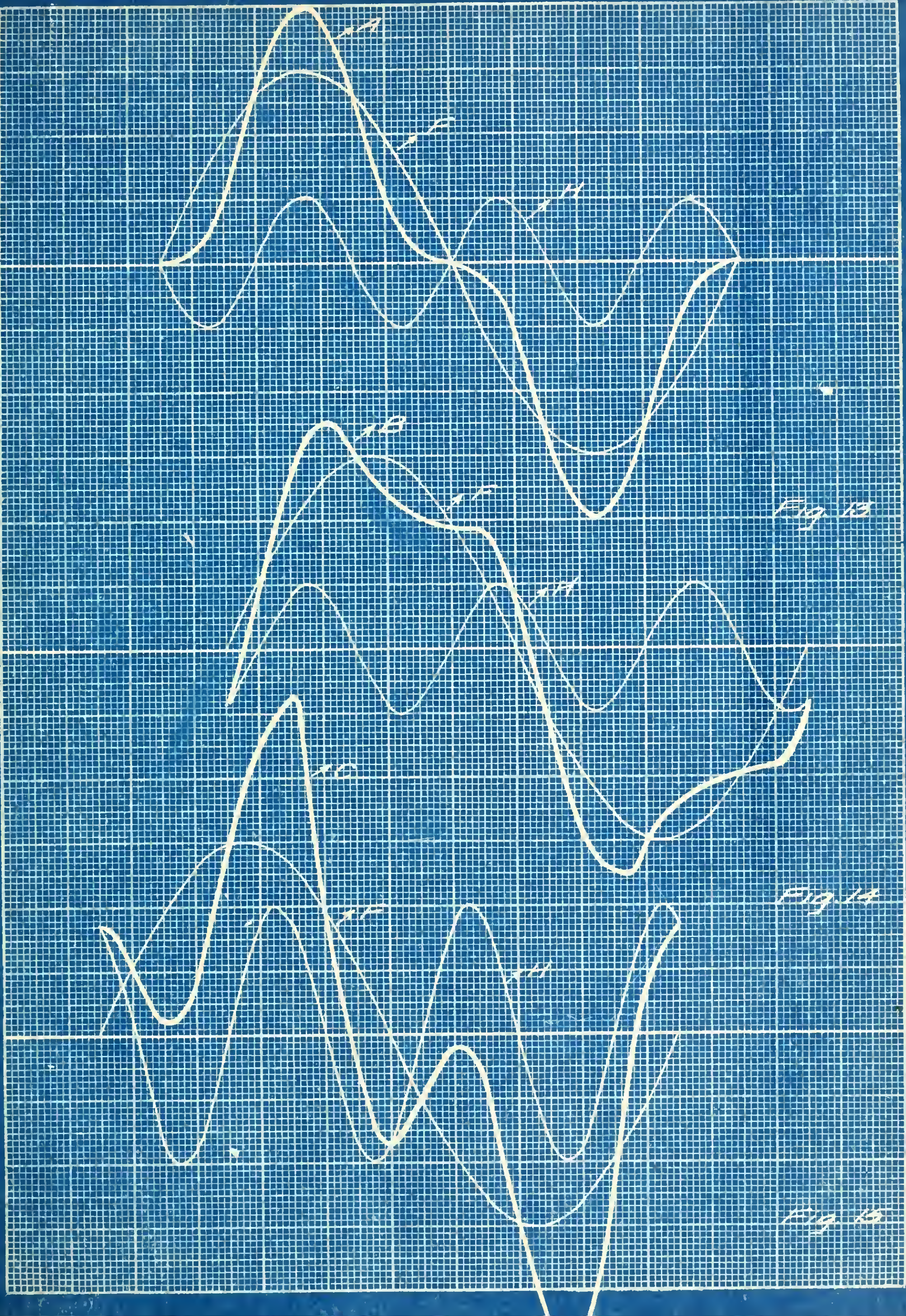


Fig. 13

Fig. 14

Fig. 15

Referring back to Figure # 7 which is for non-inductive load, it is seen that the resultant magnetism OM is larger on one side of the circle OMA than it is on the ether,thus the E.M.F. is greater on one side of the cycle,this accounts for the shape of the curve R.

In figure # 14 the phase angle has been taken at a lag of forty degrees.The fundamental and harmonic are displaced as shown, and the curve B is compounded of the two. This curve is intended to represent the current wave for an inductive load.In the oscillograph curves B, B_2 B_3,and B_4 which are for inductive loads,it is seen that the current rises very rapidly at first and then gradually decreases. Curve B figure # 14closely represents the true curves.If however the correct angle of lag,the correct number of higher harmonics,and the correct value for the amplitude,were taken a curve might be constructed which would more closely resemble the true current wave.It is beyond the scope of this paper to construct such a theoretical curve;it is intended only to explain the distortion of the curve for different loads.

In figure # 15 the current is given a lead of forty degrees. When the E.M.F. is applied to a condenser there is a greater emphasis on the harmonics.Hence in this case the amplitude of the harmonics has been increased.The fundmental and harmonic are here displaced as shown and curve C is compounded of these two.This curve more nearly resembles the condenser curves obtained with the oscillograph.

By choosing larger amplitude for the harmonics a curve would be obtained which would closely resemble the true wave.

For the same load the shape of the curves for each generator are very similiar.It is seen that by increasing the number of ringers in circuit the change in the shape of the curve is hardly noticeable.This is due to the fact that the generator has a large inductance,and by increasing the number of ringers the increase of the inductance in the circuit is comparatively small.When condensers are in circuit the curve is greatly distorted and is even more sowith only one condenser in circuit than with four.It is seen that the frequency of the current is about doubled .This fact might suggest the use of condensers for selective ringing ,Where it is desired to change the frequency .

With condensers and ringers together in the circuit, a neutralizing effect is produced and the curve is less distorted. The curve of least distortion was obtained with four ringers and four condensers in circuit.With only one ringer and two, three,and four condensers in circuit the curve becomes more distorted,since the condenser effect is increased.

The following blue prints show the shapes of the current waves as obtained with the General Electric Oscillograph.

The following is the notation used to designate each curve.

R---Non-inductive Resistance of 1192 Ohms.

B_1--One Ringer in circuit.

B_2--Two Ringers in parallel.

B_3--Three ringers in parallel.

B_4--Four ringers in parallel.

C_1--One condenser in circuit.

C_2--Two condensers in parallel.

C_3--Three condensers in parallel.

C_4--Four condensers in parallel/

B_1C_1--One ringer and one condenser in series.

B_2C_2-Two ringers and two condensers in paralell.

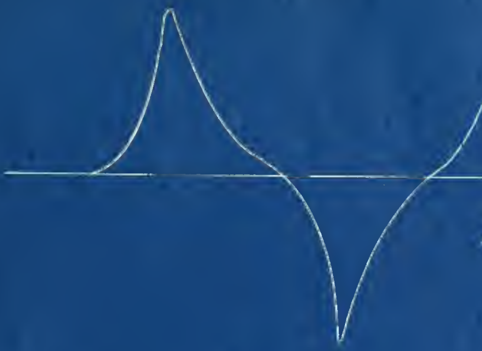
B_3C_3-Three ringers and three condensers in parallel.

B_4C_4-Four ringers and four condensers in parallel.

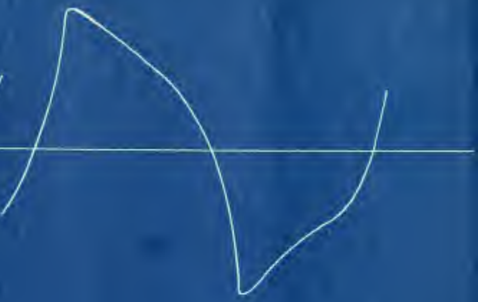
B_1C_2-Two condensers in parallel connected in series with one ringer.

B_1C_3-Three condensers in parallel connected in series with one ringer.

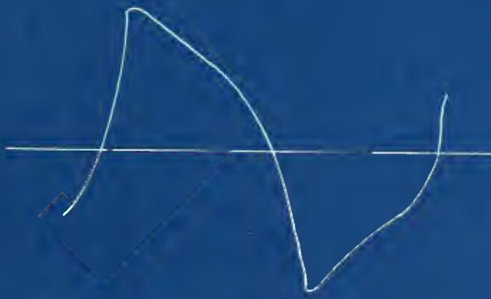
B_1C_4-Four condensers in parallel connected with one ringer.



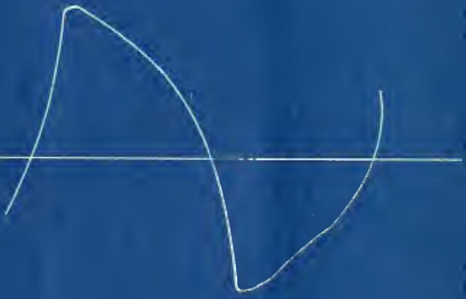
A



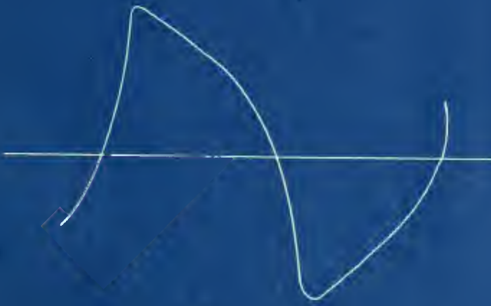
B_1



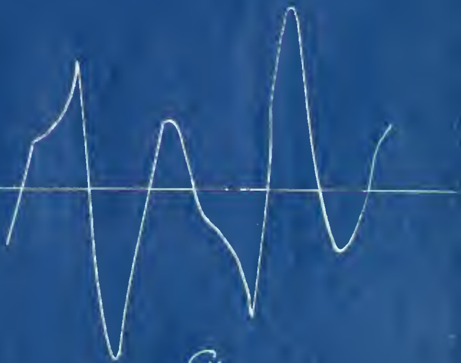
B_2



B_3

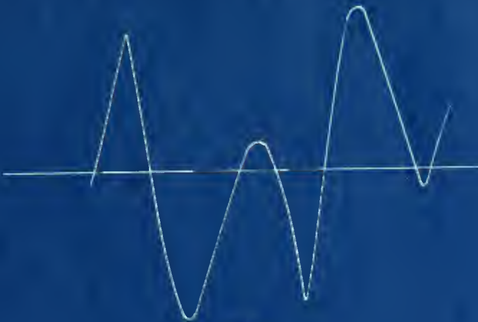


B_4

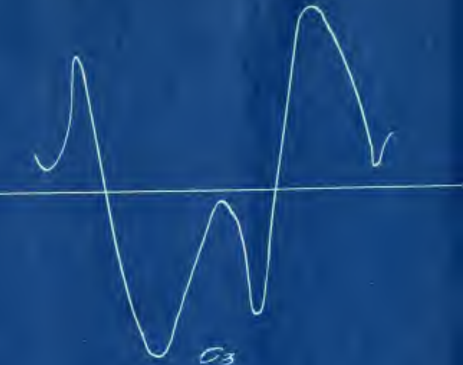


C_1

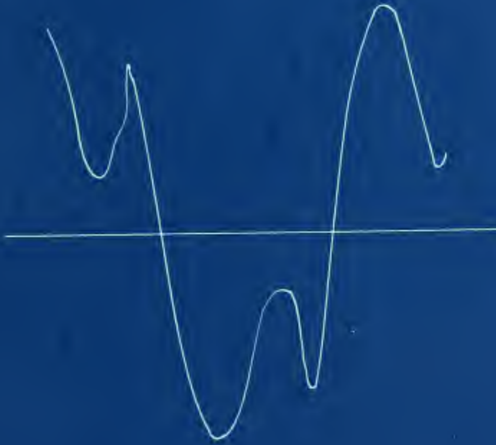
No. 1



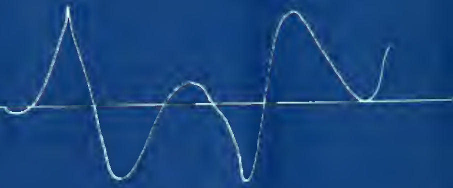
C_2



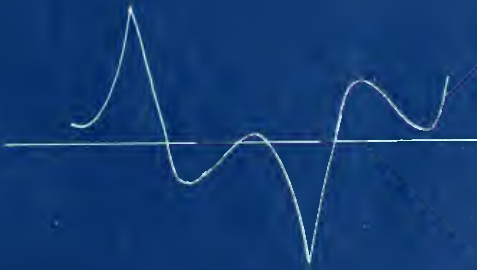
C_3



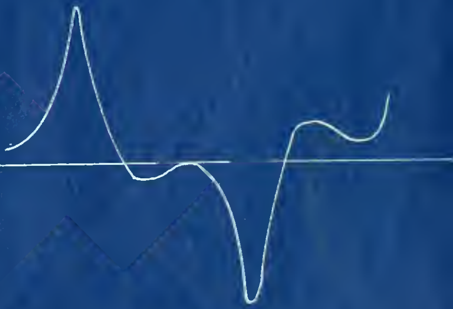
C_4



$C_1 B_1$

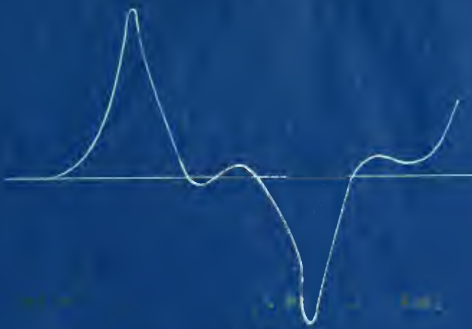


$C_2 B_2$

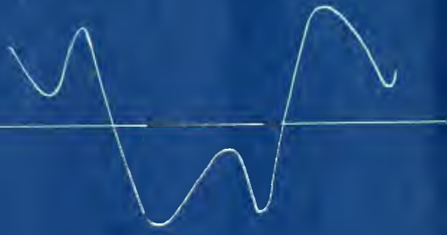


$C_3 B_3$

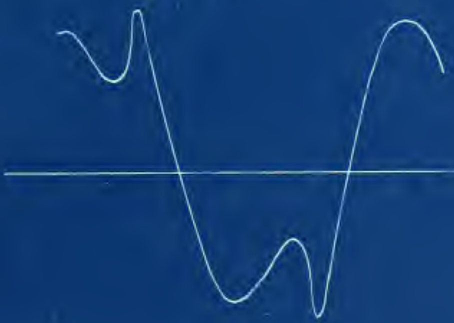
No. 1



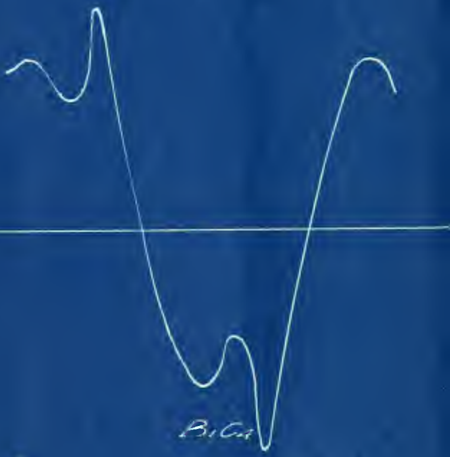
C_4,B_4



B_1C_2

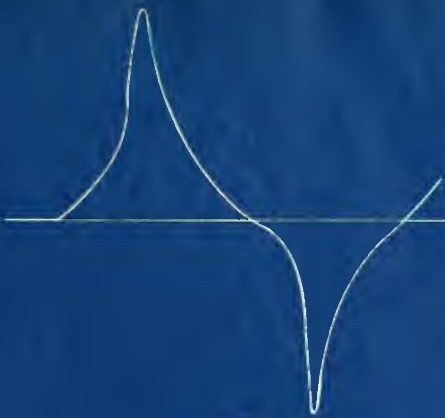


B_1C_3

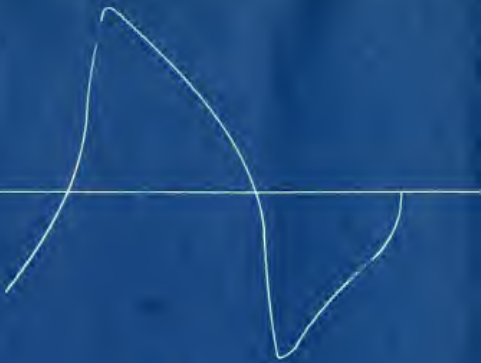


B_1C_4

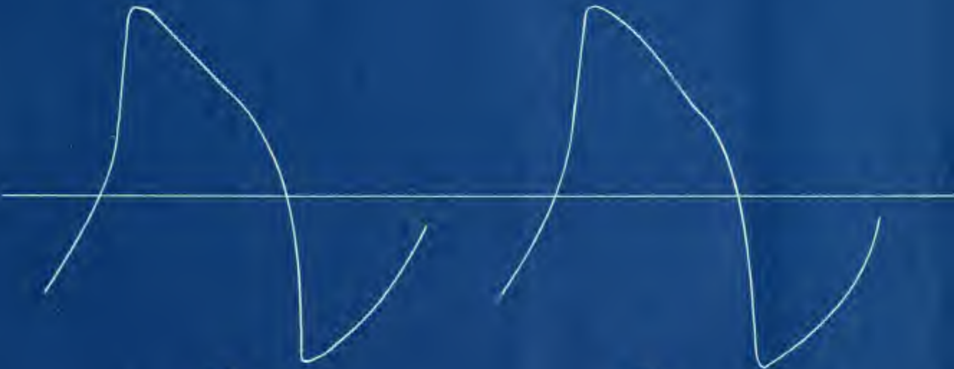
No. 2



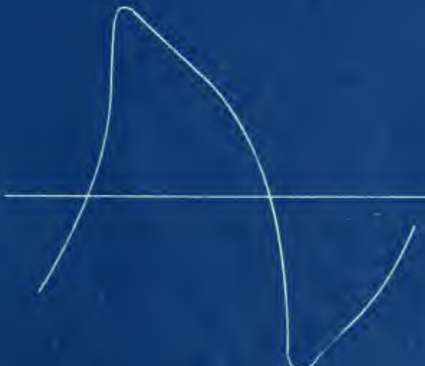
R



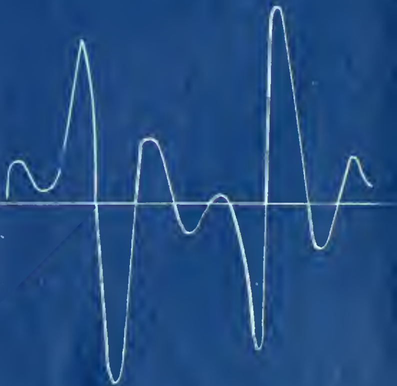
B_1



B_2 B_3

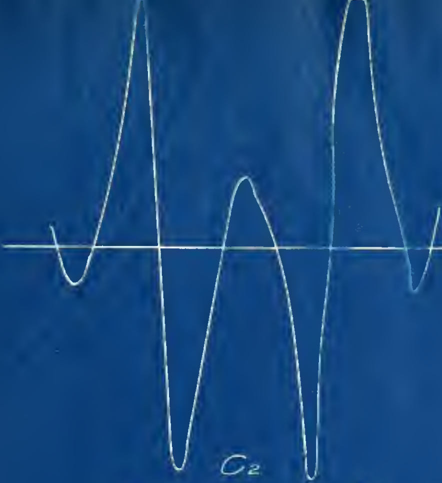


B_4

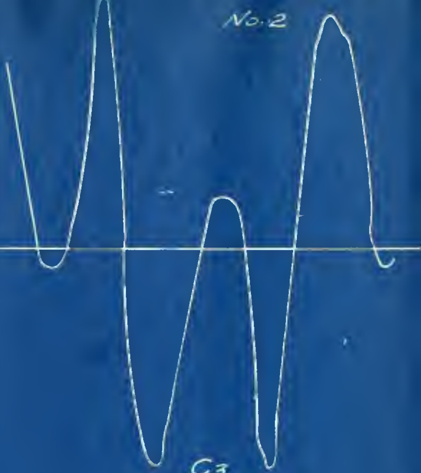


C_1

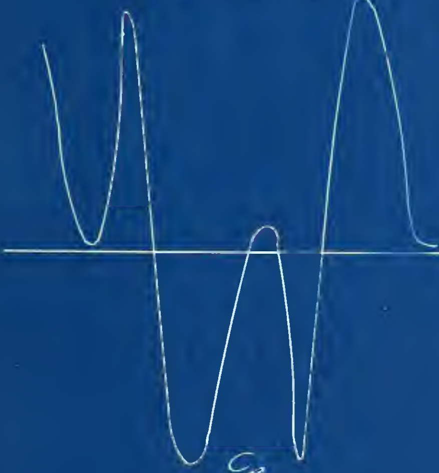
No. 2



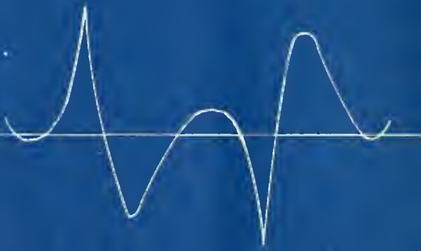
C2



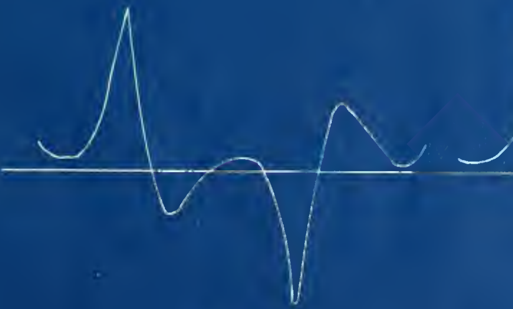
C3



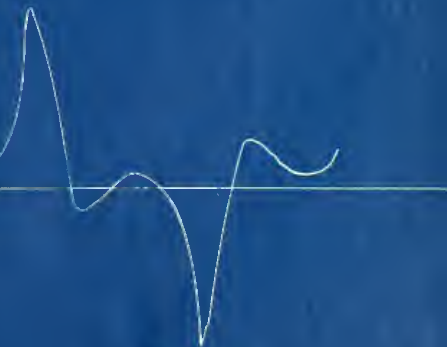
C4



C1 B1

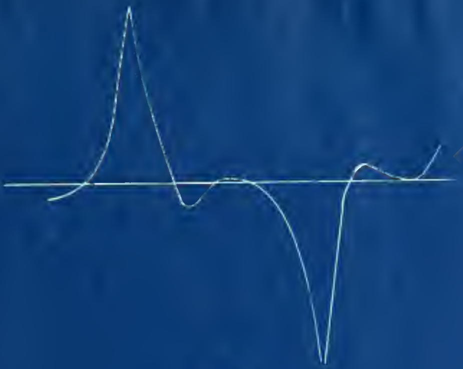


C2 B2

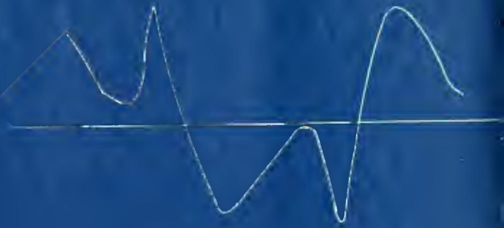


C3 B3

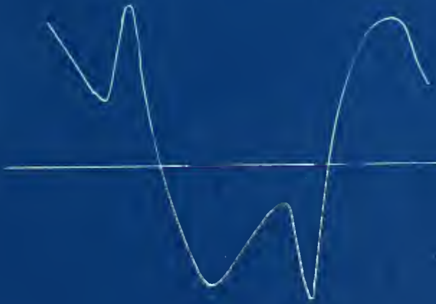
No. 2



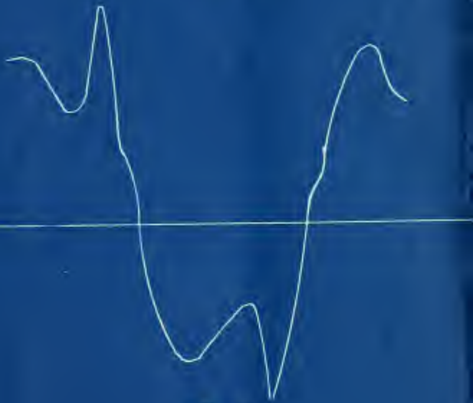
C_4B_4



B_1C_2

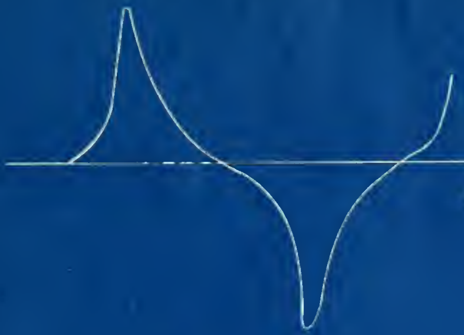


$B_1 C_3$

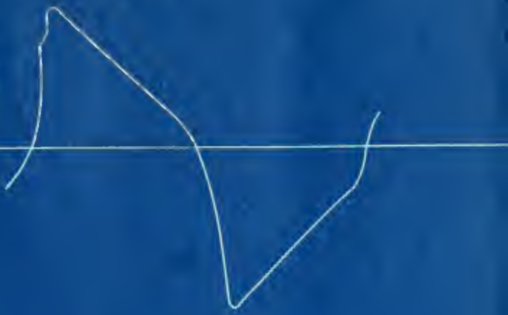


B_1C_4

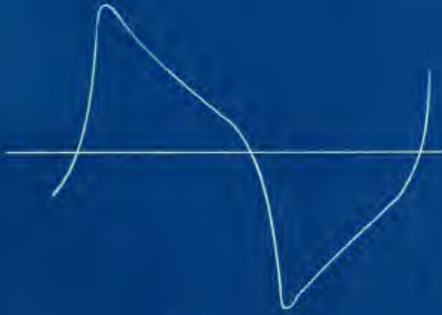
No. 3



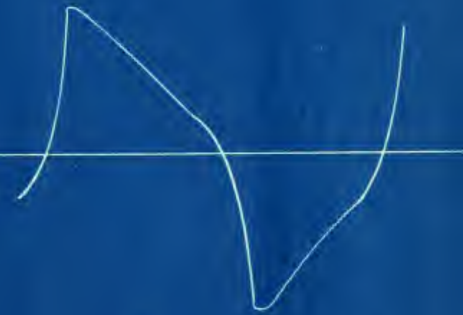
R



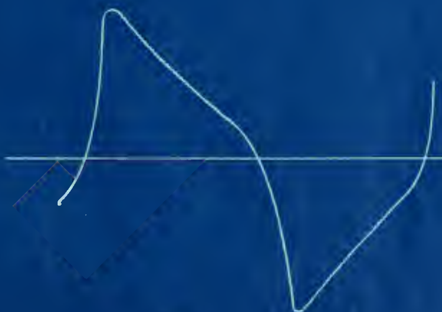
B1



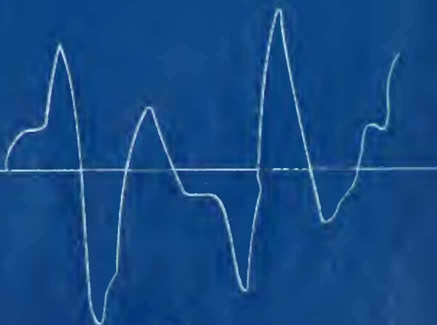
B2



B3

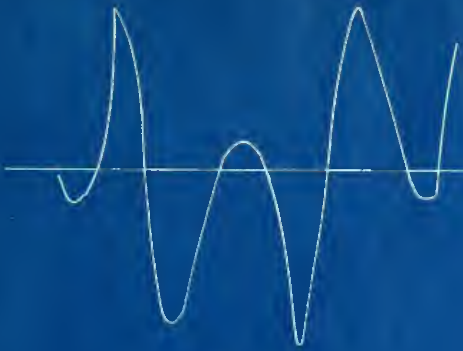


B4

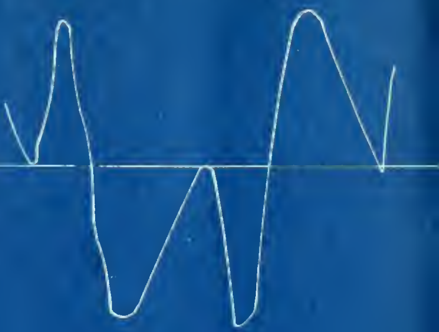


C1

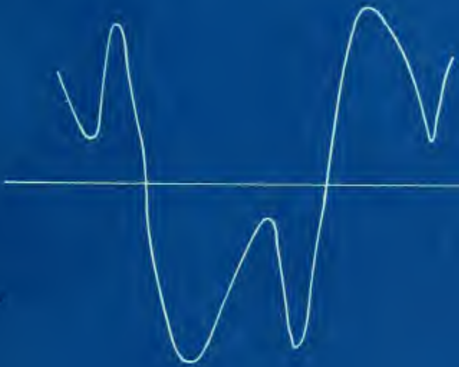
No. 3



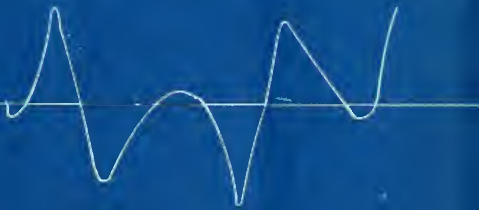
C_2



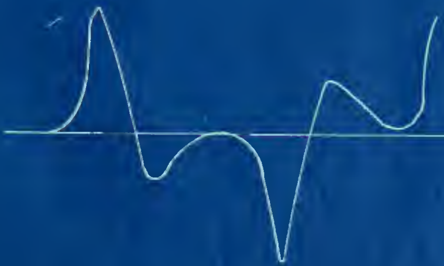
C_3



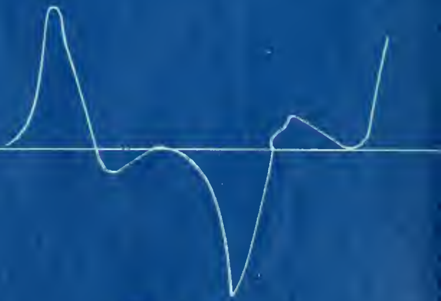
C_4



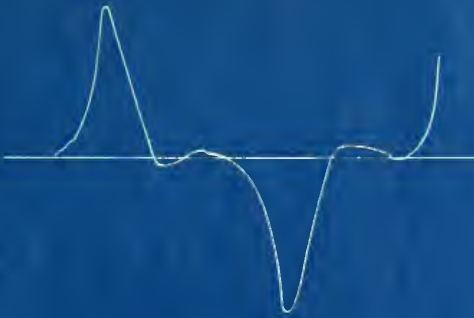
C_1B_1



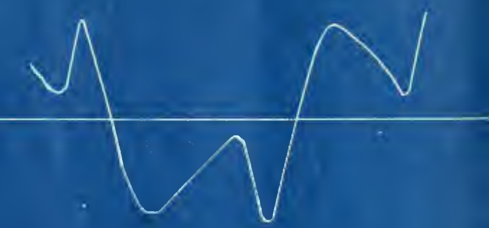
C_2B_2



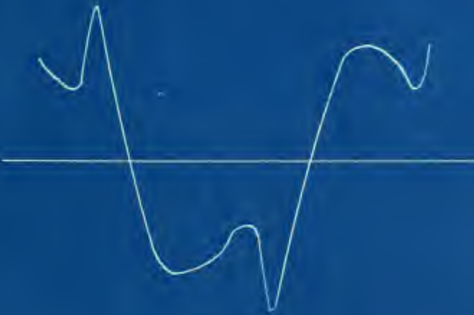
C_3B_3



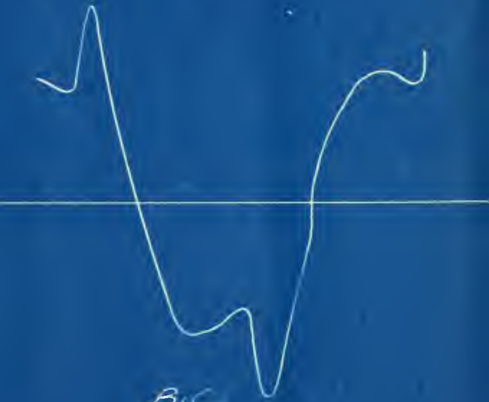
C_4B_4



B_1C_2

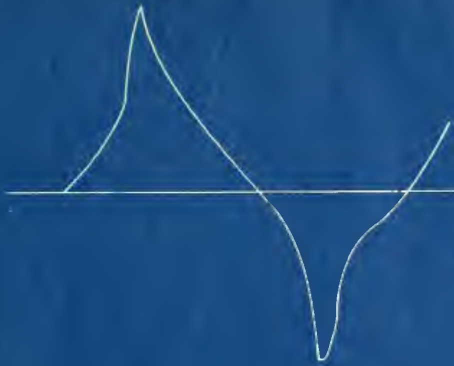


B_1C_3

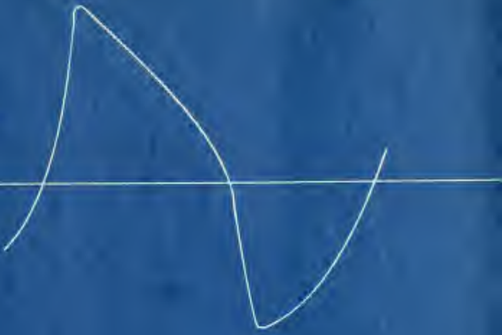


B_1C

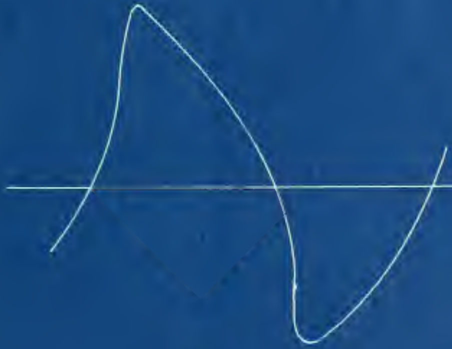
No. 4



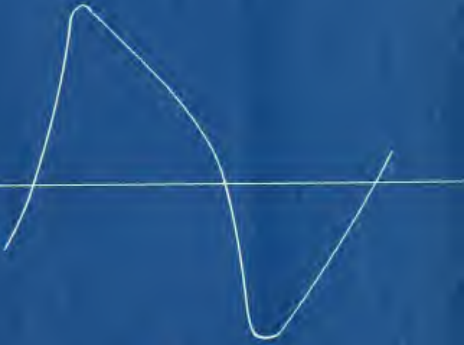
A



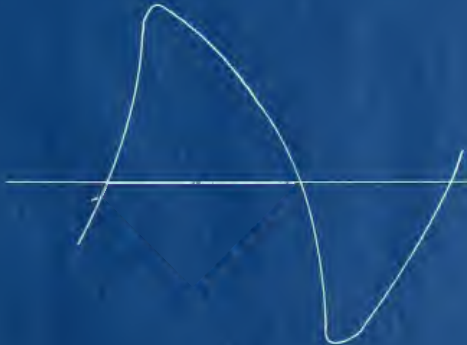
B1



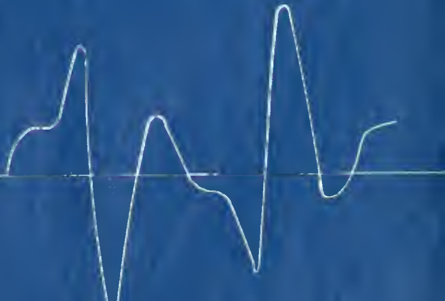
B2



B3

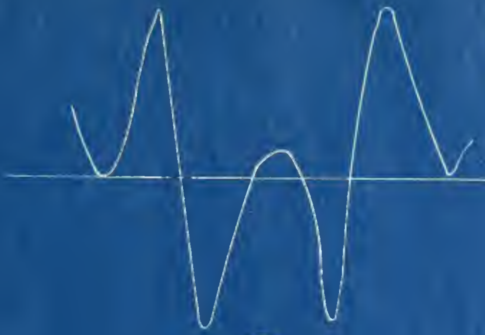


B4

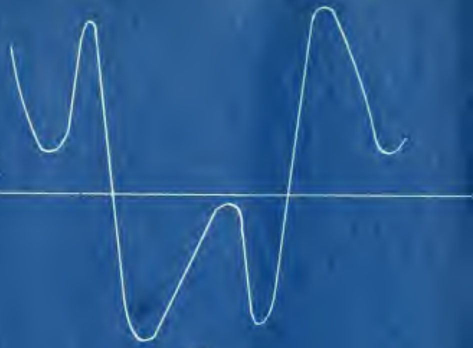


C1

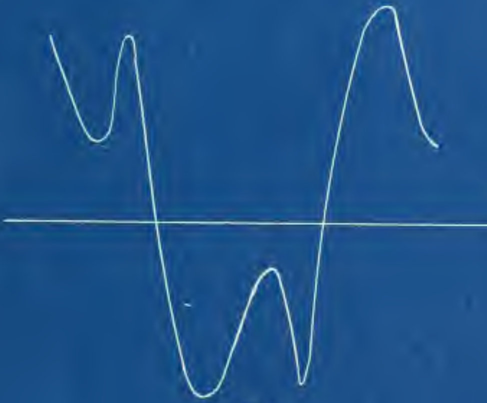
No. 4



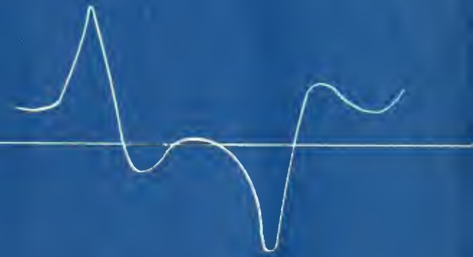
C_2



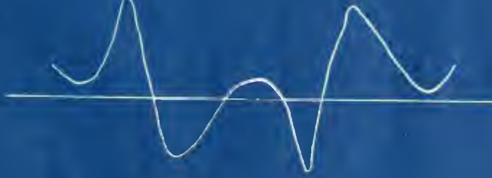
C_3



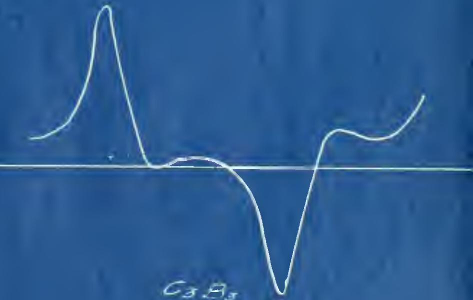
C_4



$C_2 B_2$

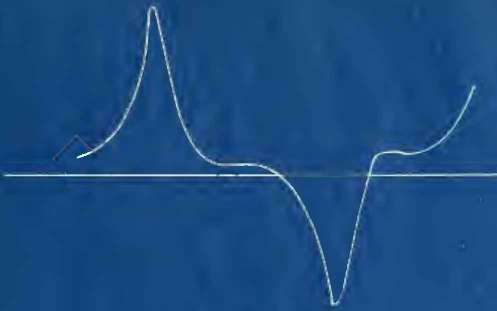


$C_1 B_1$

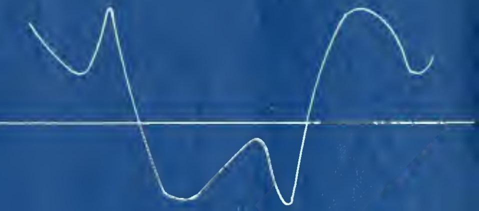


$C_3 B_3$

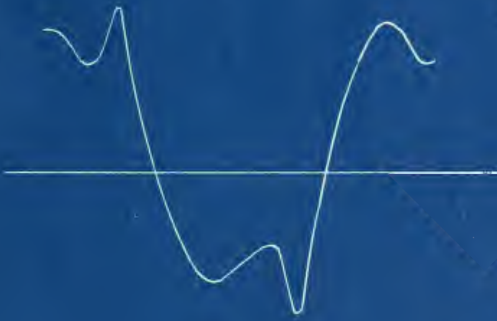
No. 4



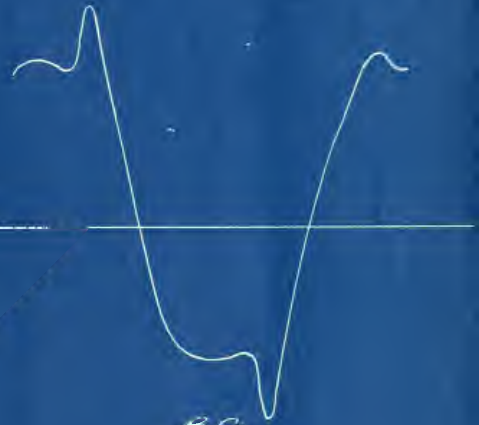
$C_4 B_4$



$B_1 C_2$

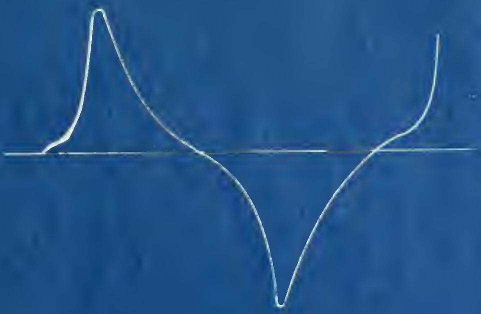


$B_1 C_3$

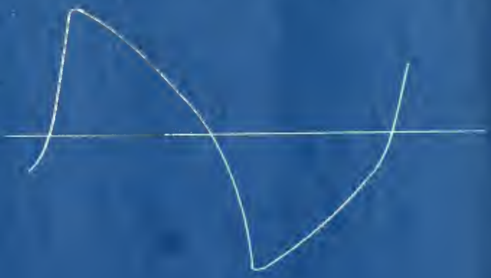


$B_1 C_4$

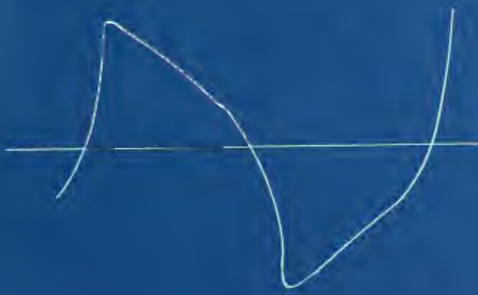
No. 5



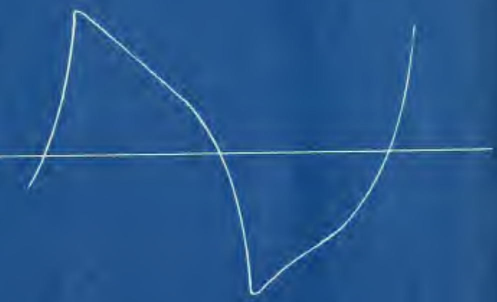
R



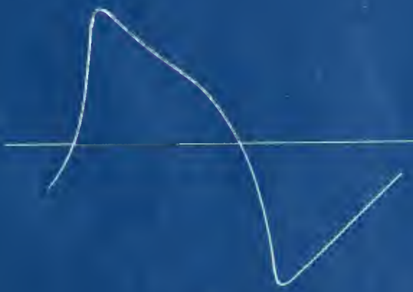
B_1



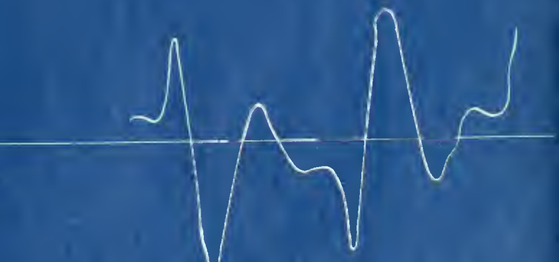
B_2



B_3

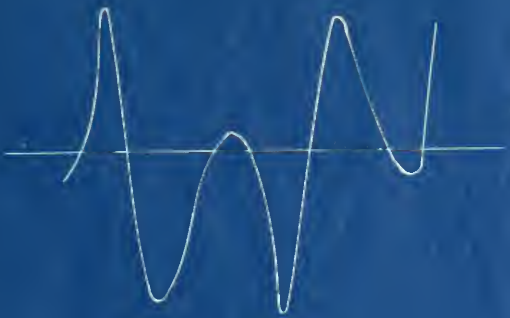


B_4

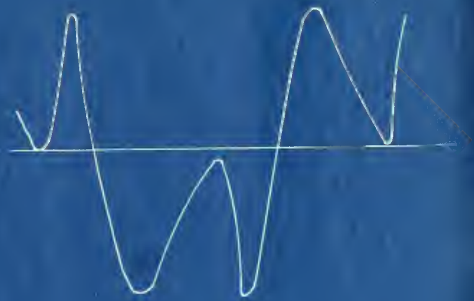


C_1

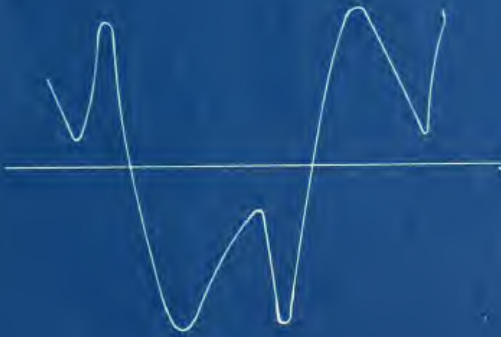
No. 5



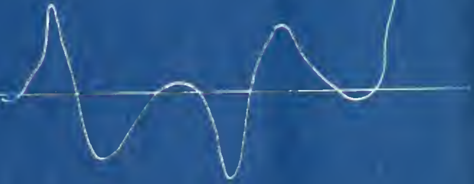
C_2



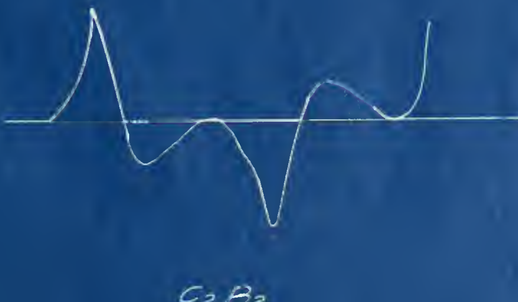
C_3



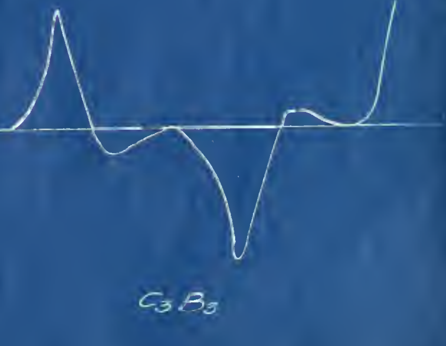
C_4



$C_1 B_1$

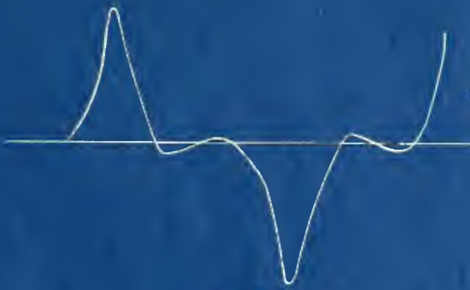


$C_2 B_2$

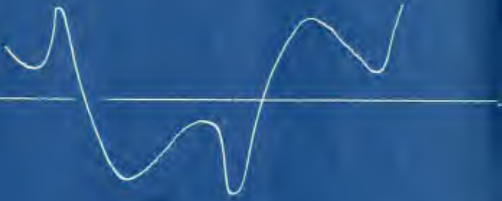


$C_3 B_3$

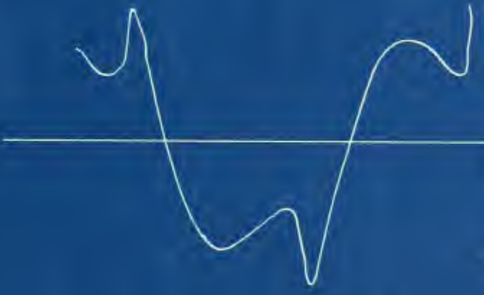
No. 5



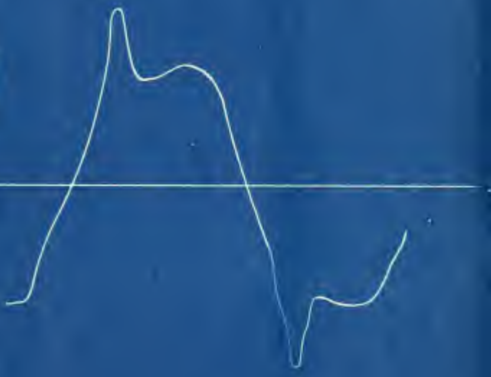
C_4B_4



B_1C_2

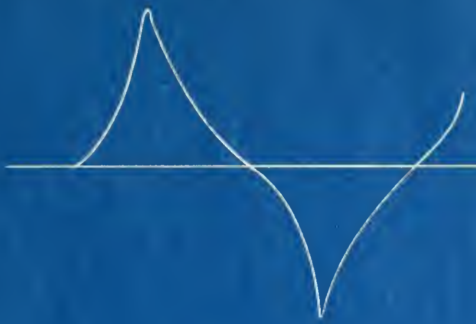


C_3B_3

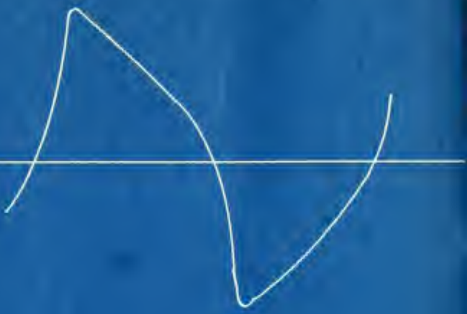


B_1C_4

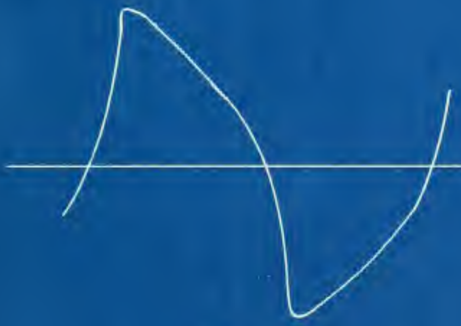
No. 6



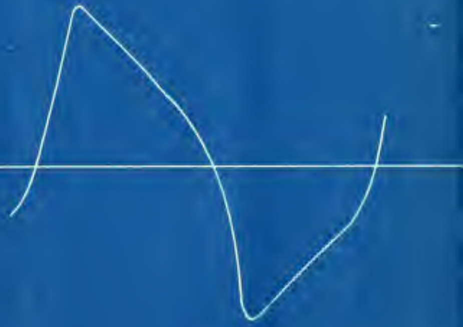
A



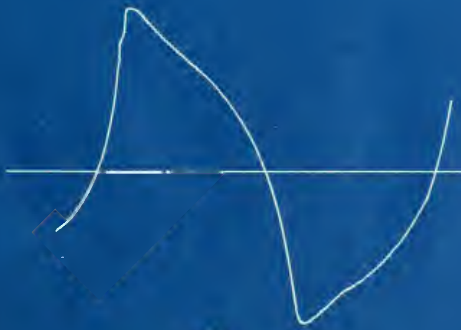
B1



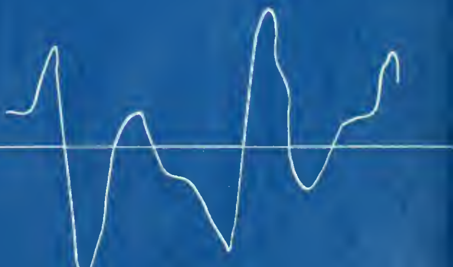
B2



B3

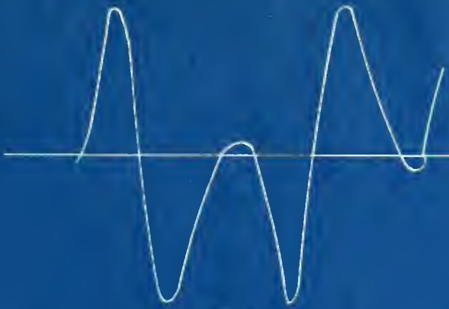


B4

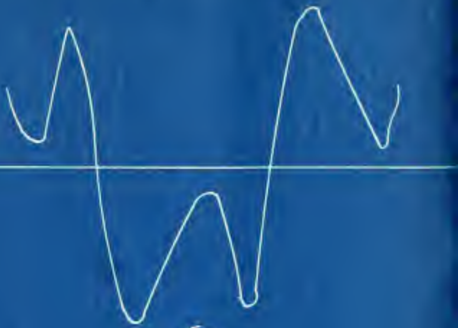


C1

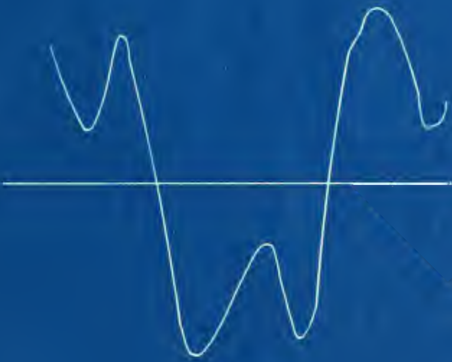
No. 6



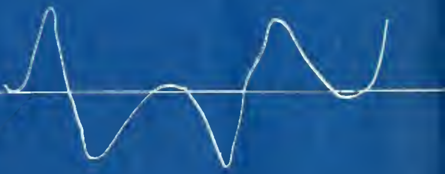
C_2



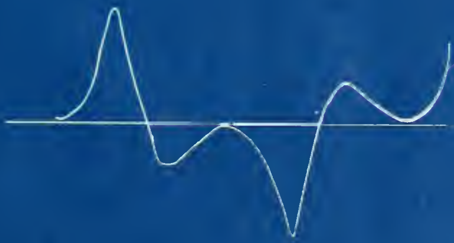
C_3



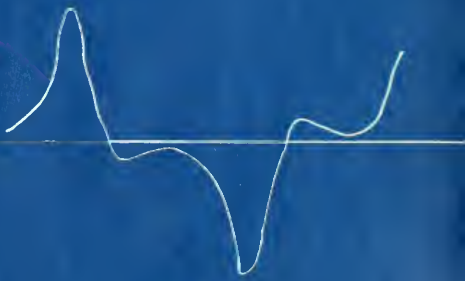
C_4



$C_1 B_1$

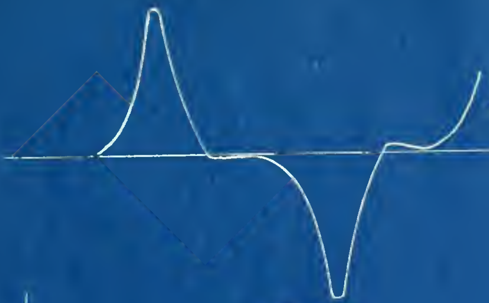


$C_2 B_2$

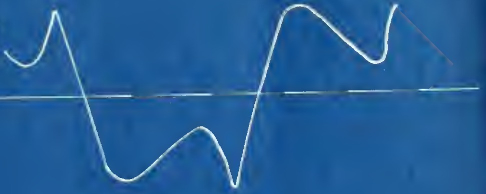


$C_3 B_3$

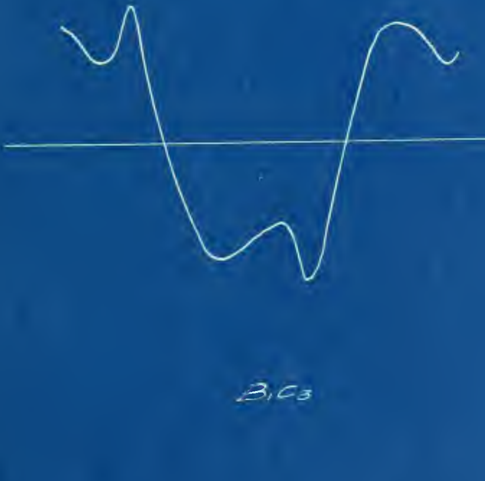
No. 6



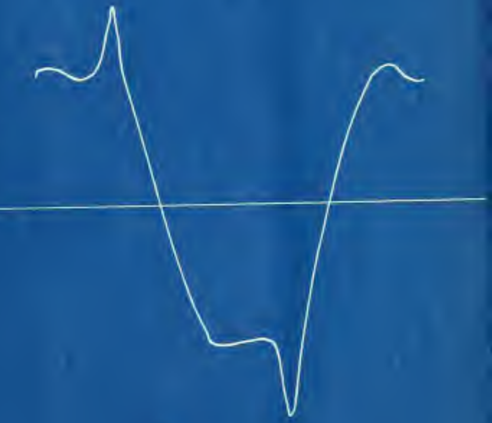
C_1B_1



B_1C_2

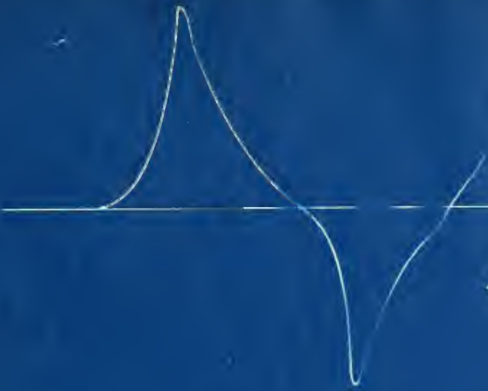


B_1C_3

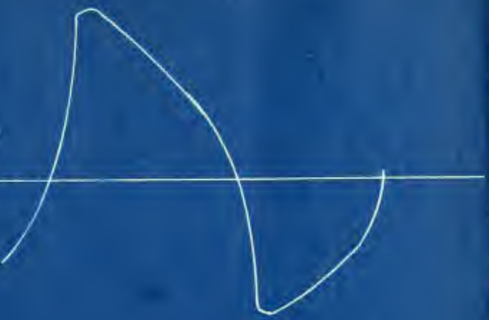


B_1C_4

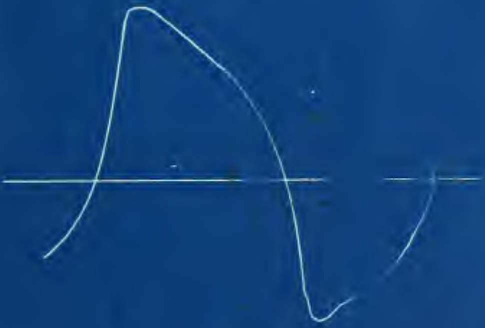
No. 7



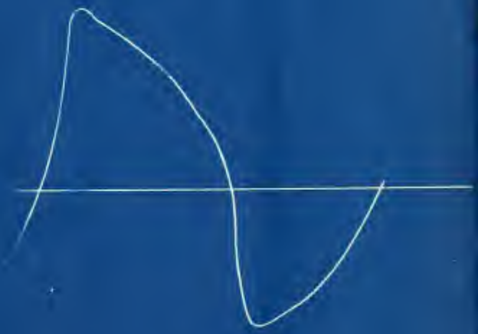
A



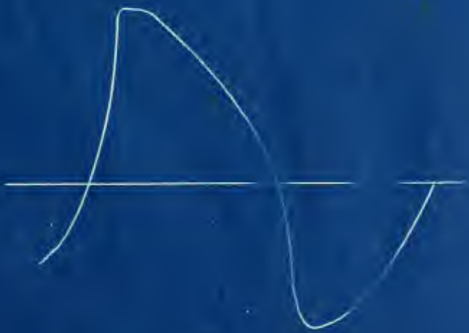
B1



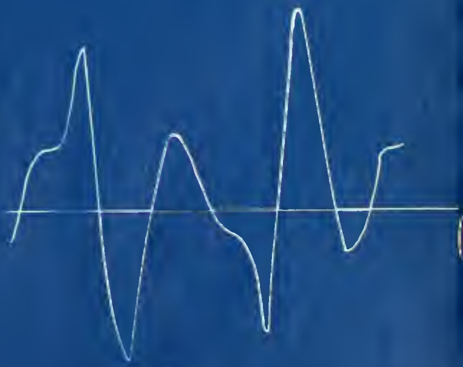
B2



B3

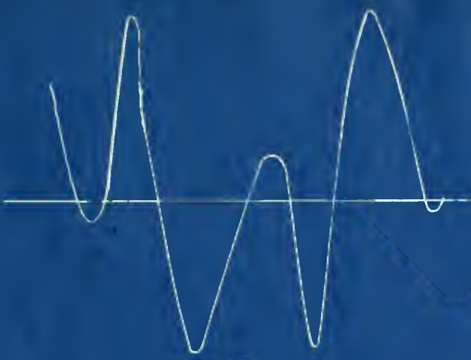


B4

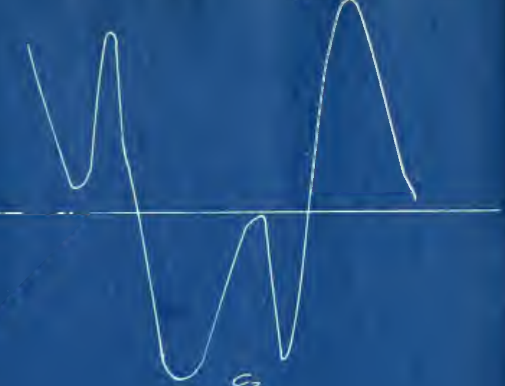


C1

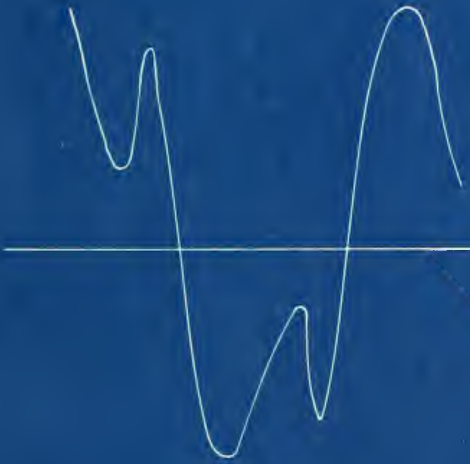
No. 7



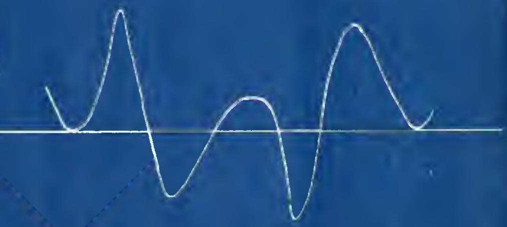
C_2



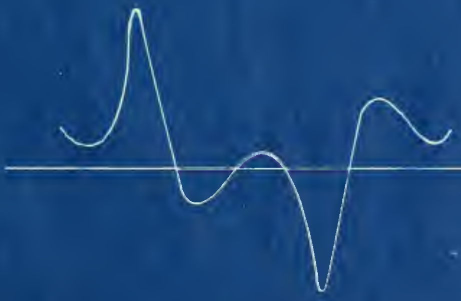
C_3



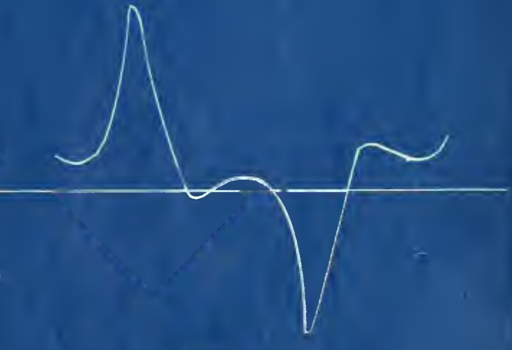
C_4



$C_1 B_1$

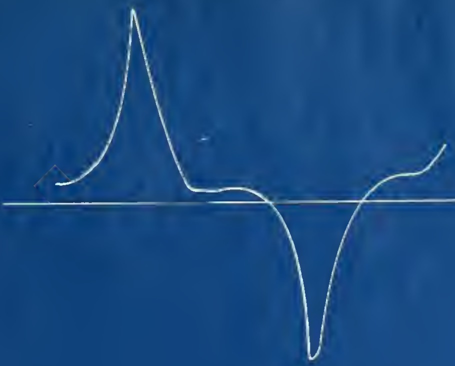


$C_2 B_2$

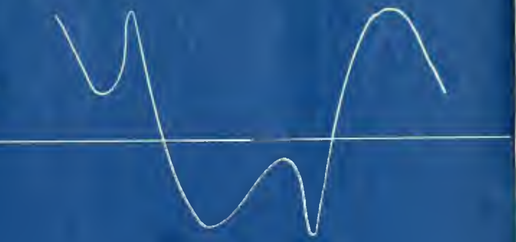


$C_3 B_3$

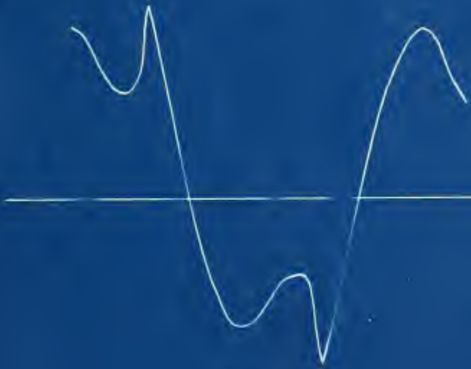
No. 7



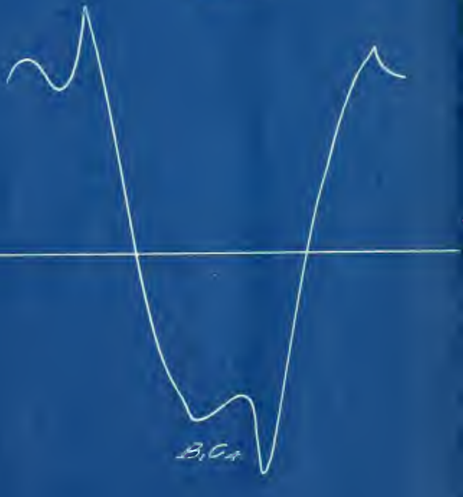
B_4C_4



B_1C_2

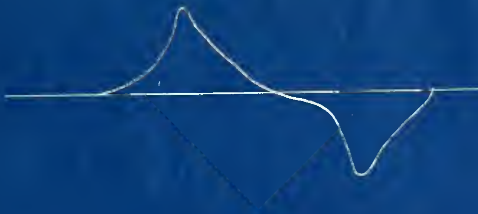


B_1C_3

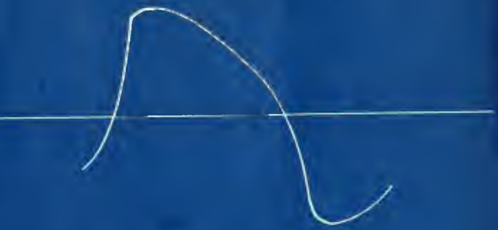


B_1C_4

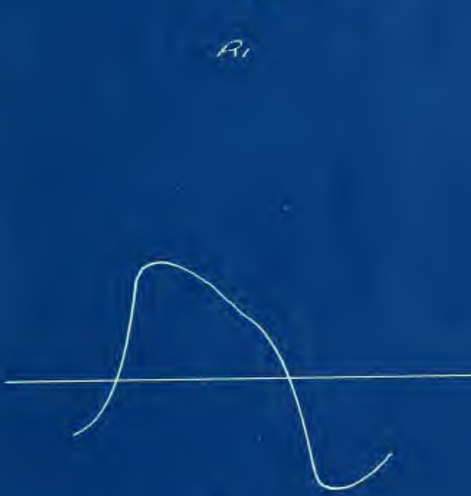
No. 8



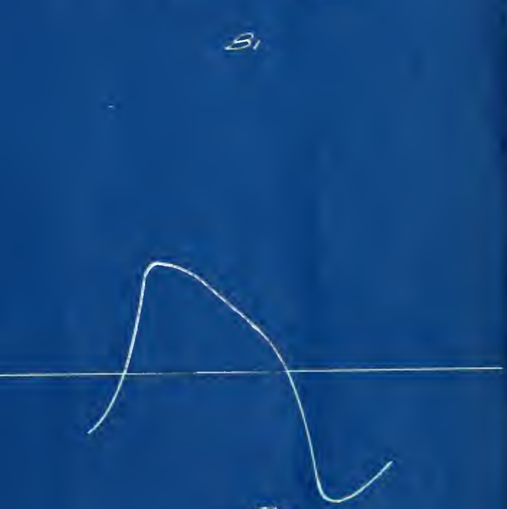
A1



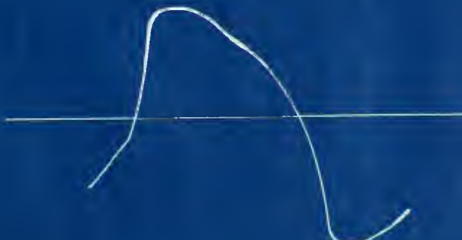
B1



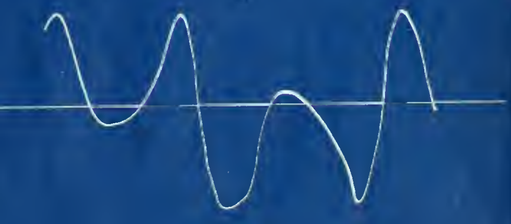
B2



B3

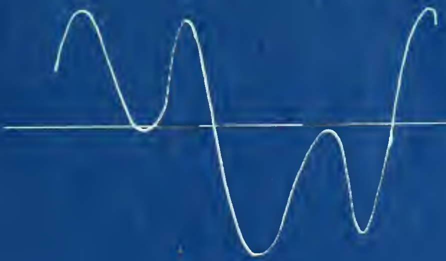


B4

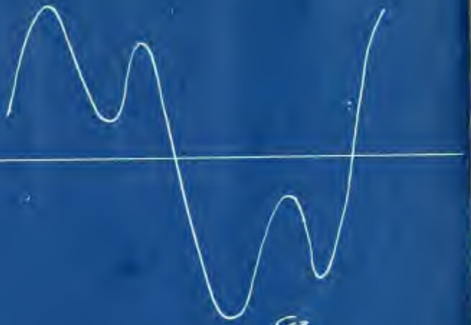


C1

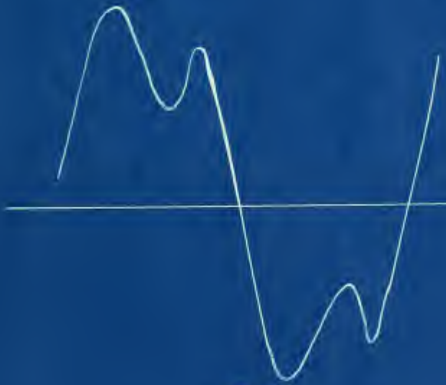
No. 8.



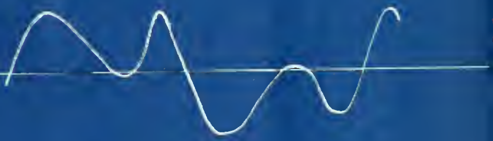
C_2



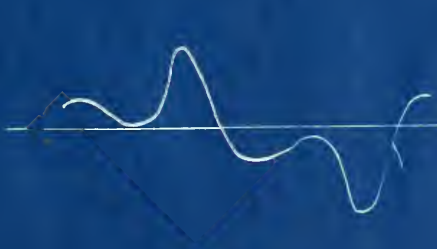
C_3



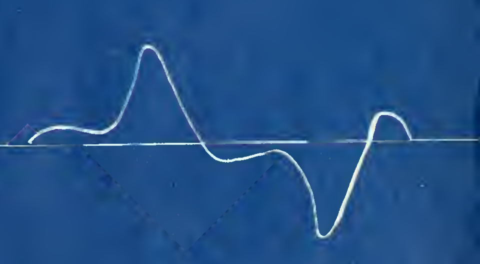
C_4



C_1B_1

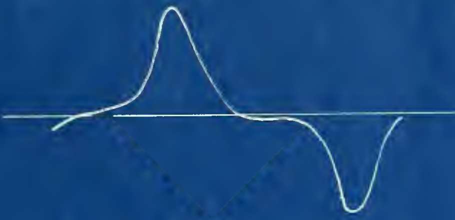


C_2B_2

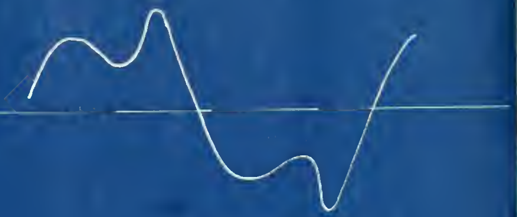


C_3B_3

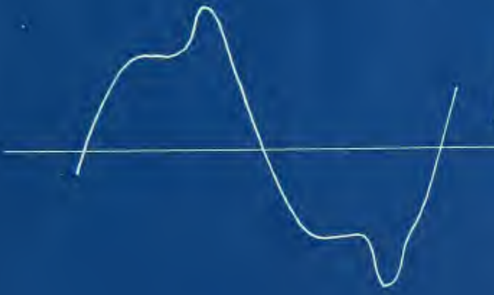
No. 8



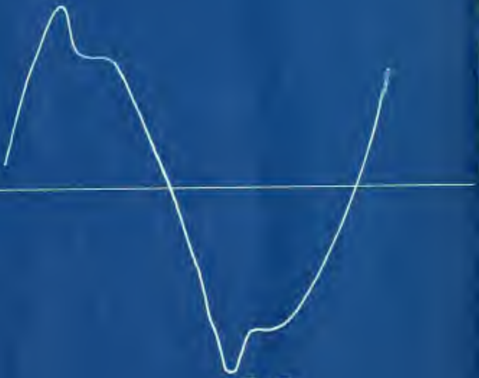
C_4B_4



B_1C_2

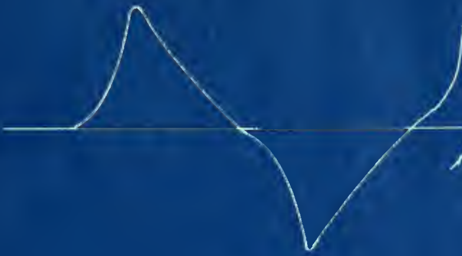


B_1C_3

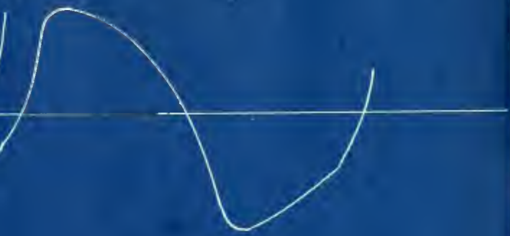


B_1C_4

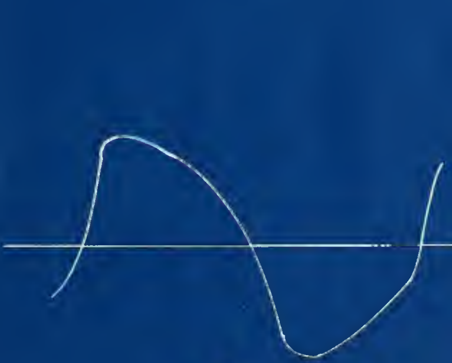
No. 9



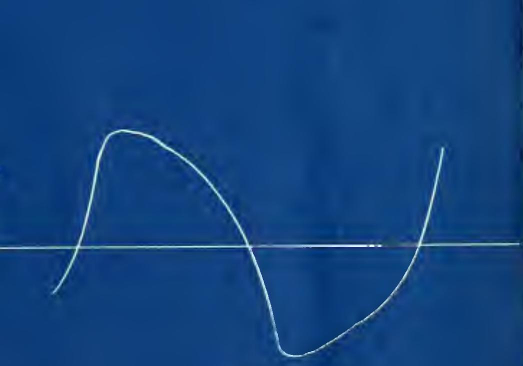
A



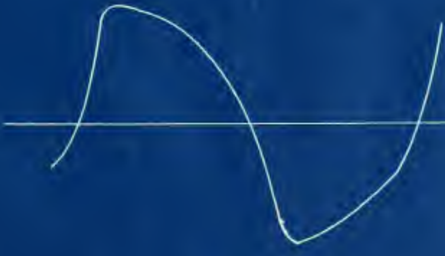
B_1



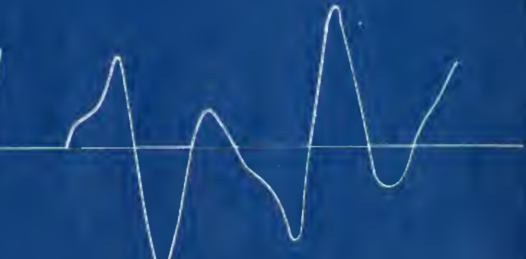
B_2



B_3

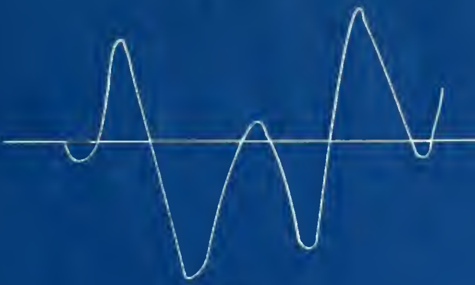


B_4

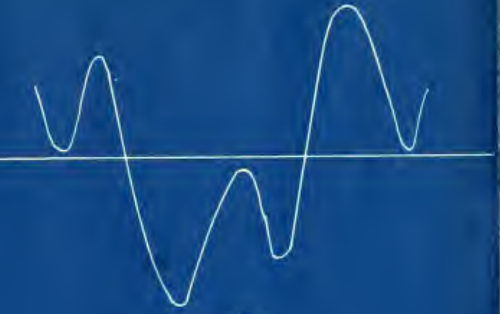


C_1

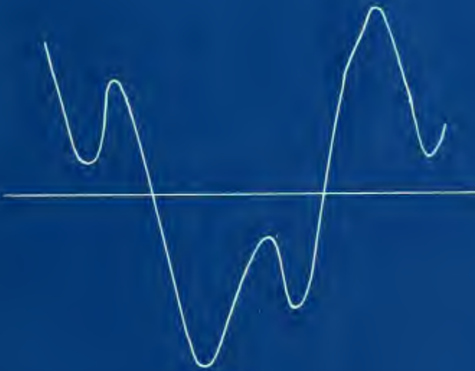
No. 9



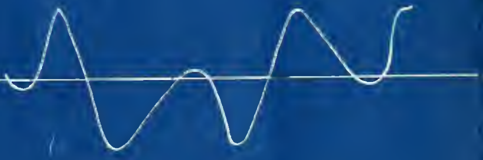
C_2



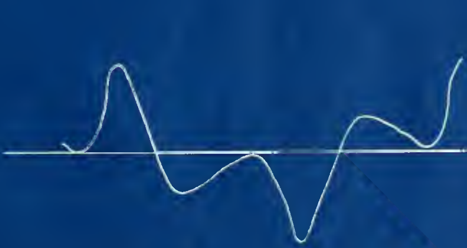
C_3



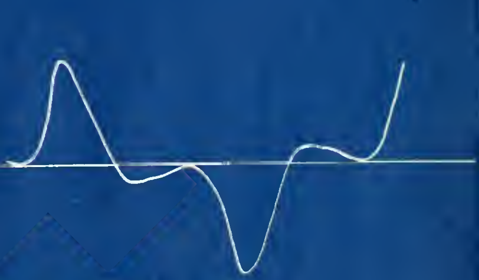
C_4



C_1B_1

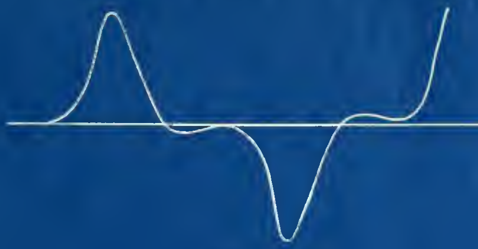


C_2B_2

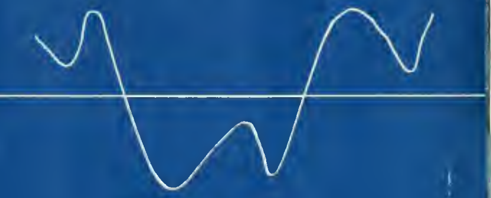


C_3B_3

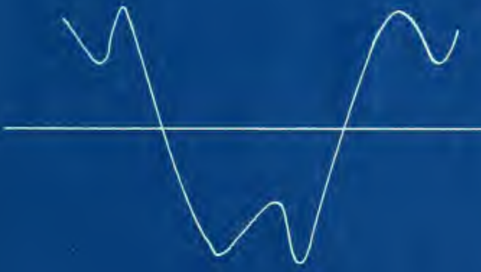
No. 9



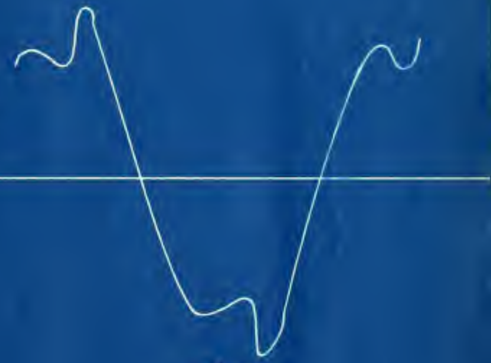
C_4B_4



B_1C_2

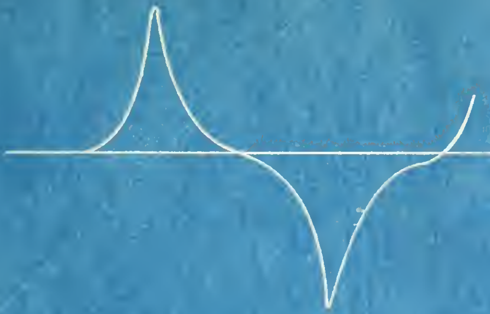


B_1C_3

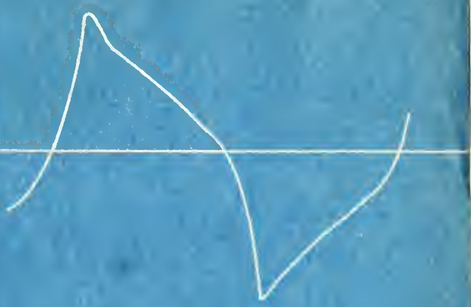


B_1C_4

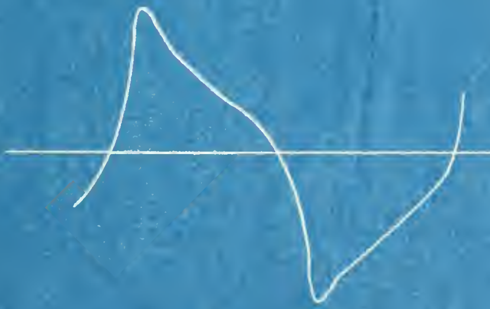
No. 10



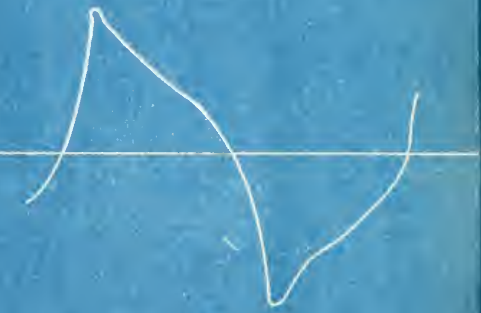
A



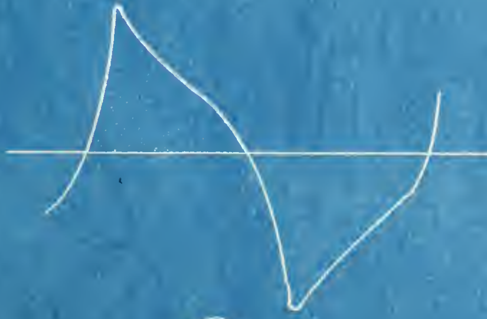
B1



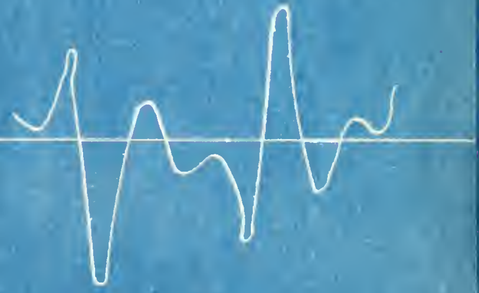
B2



B3

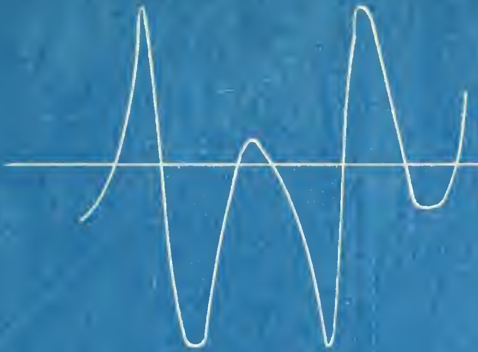


B4

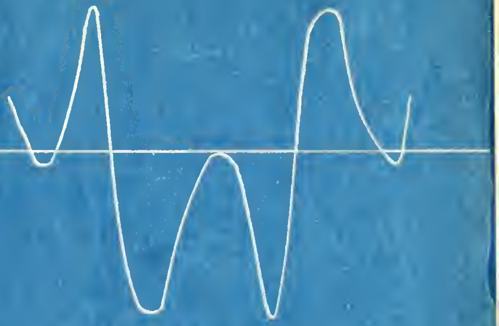


C1

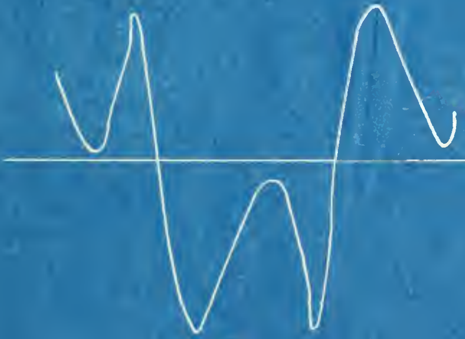
No. 10



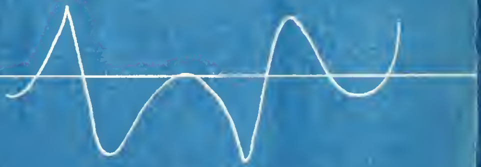
C_2



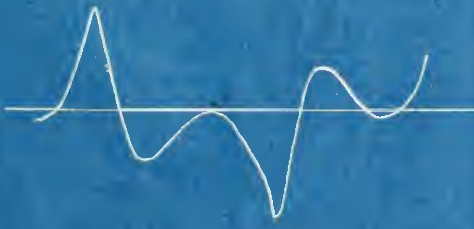
C_3



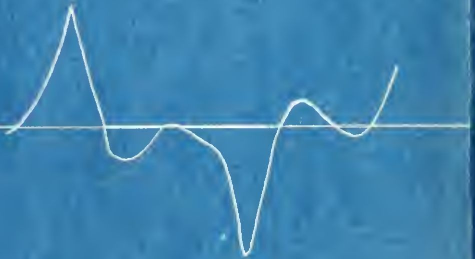
C_4



C_1B_1

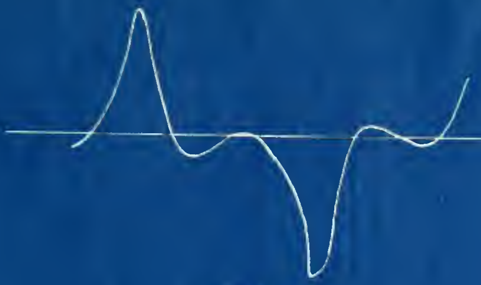


C_2B_2

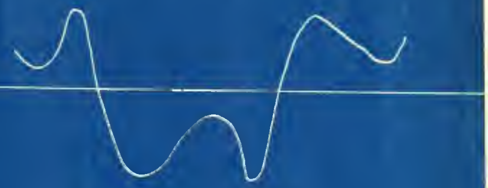


C_3B_3

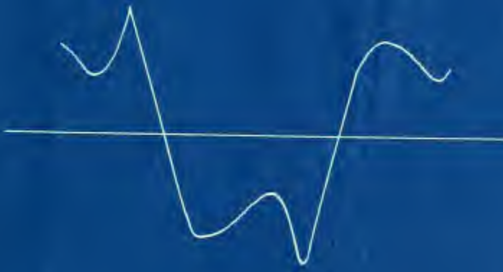
No. 10



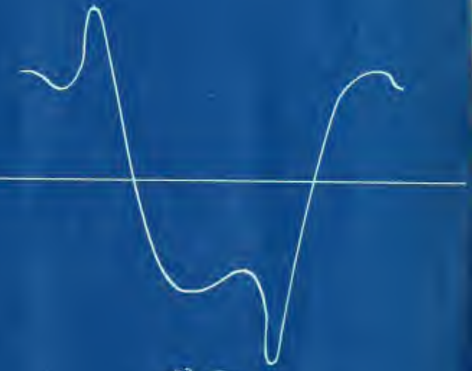
C_4B_4



B_1C_2



B_1C_3



B_1C_4